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DOCUMENTATION FOR HARO3

A COMPUTER PROGRAM FOR THE MODELING OF WATER QUALITY
PARAMETERS IN STEADY STATE MULTI-DIMENSIONAL NATURAL
AQUATIC SYSTEMS

ENVIRONMENTAL PROTECTION AGENCY

OCTOBER 1974

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documentation for

HAR03

"A computer program for the modeling of water quality
parameters in steady state multi-dimensional
natural aquatic systems"

SECOND EDITION

prepared by

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October, 1974

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ABSTRACT

- definition : HAR03 is a computer program which can be used to model the steady-state distribution of water quality variables for multi-dimensional bodies of water. The technique underlying the program is based on the conservation of mass and up to two variables reacting in a feed forward fashion with first order kinetics may be modeled.
- computer : HAR03 has been designed for an IBM 370 computer, requires approximately 184 K of core to compile and was written for a Fortran IV G or H Level compiler.
- application : HAR03 has been designed with the Biochemical Oxygen Demand (BOD) - Dissolved Oxygen system in mind.

With minor modification the program may be used to model other variables which are analogous to this system such as chlorides, polyphosphate - orthophosphate, coliform bacteria, etc.

In order to save core for small systems, HAR03 has been compiled in three versions. The first version handles a system of up to 50 segments and is designated HAR50; similarly HAR100 and HAR200 handle a maximum of 100 and 200 segments correspondingly. The only difference between these versions is in the size of the arrays defined in the programs.

INTRODUCTION

The formulation of a mathematical model of any system is greatly determined by two factors: the nature of the system itself and the purposes and perspective of the investigator. The modeler must strike a balance between objective reality and the subjectivity of his needs to attain a successful analysis. This problem is further compounded when dealing with the high complexity of the natural world.

One of the more prevalent misconceptions among neophytes in the field of water quality modeling is that there is one analytical technique which is superior in depicting the water quality in a natural body of water. This may be partially due to the fact that the field straddles several more or less hard sciences and engineering disciplines and as such can be perceived from a variety of perspectives.

For instance, hydrodynamicists, who are essentially interested in the movement of fluids, often tend to emphasize the obviously important effect of water motion on the transport of matter in a system. Ecologists and aquatic biologists on the other hand stress the equally important reactions between the community of organisms which populate the system. The danger in these or in any particular approach comes from the automatic exclusion or underestimation of viewpoints outside the area of expertise of the modeler.

One of the older approaches to water quality modeling which rather effectively incorporates a number of perspectives in representing the causal relationships of stream pollution is that of the sanitary engineering profession. Due to their interest in designing waste treatment facilities, sanitary engineers were rather early introduced to the problems of wastes and their impact on the environment. A classic study in this profession was that done by Streeter and Phelps¹ on the Ohio River in 1925.

By making a variety of simplifying assumptions in the hydrodynamic and biological areas, these investigators arrived at a very utilitarian approach to water quality analysis which still stands as a viable technique for answering many questions about the relationship between pollution and the aquatic environment of a stream. In the hydrodynamic area, they assumed that the waste load was delivered by a pipe into a channel which could be described as having constant geometrical dimensions and constant flow. As well it was assumed that the pollutant was instantaneously mixed in the lateral and vertical directions and that the simple continuity equation, $Q=AV$, applied. From the biological standpoint, it was decided that a chemical parameter upon which most species depend for life, namely, dissolved oxygen could be modeled as an indicator of the health of the biota. To do this, they had to use a measure of the oxygen demand of the waste, the biochemical oxygen demand (BOD), as the input to the system and formulated relationships between dissolved oxygen and BOD in terms

of first order kinetics. The result is what is now called the Streeter-Phelps equation which in its basic form is:

$$D = \left[\frac{K_d}{K_a - K_r} (e^{-K_r x/u} - e^{-K_a x/u}) \right] L_0 + D_0 e^{-K_a x/u} \quad \text{.....(I-1)}$$

where:

D =dissolved oxygen deficit= $DO_s - DO$

DO_s =saturation concentration of dissolved oxygen

DO =actual concentration of dissolved oxygen

L_0 =initial concentration of BOD at point of introduction of waste

D_0 =initial concentration of dissolved oxygen deficit at point of introduction of waste

K_r =BOD removal rate

K_d =Deoxygenation rate

K_a =Reaeration rate

U =stream velocity

x =distance downstream from point of introduction of waste

The result of the Streeter-Phelps equation is called the "D.O. sag" and is illustrated in figure I-1.

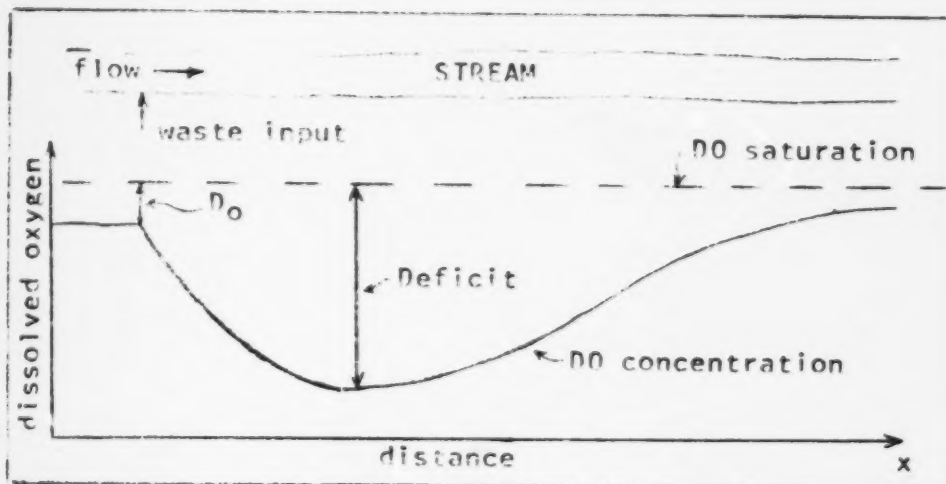


Figure I-1: D.O. sag generated by Streeter Phelps equation

This environmental model is ideal for the evaluation of various treatment schemes as its basic control variable is the waste input. This emphasis on relating man's waste inputs to the aquatic environment with the express purpose of managing the inputs and thus the water quality is what typifies the sanitary engineering approach. This can be contrasted with an aquatic biologist who might be more interested in the interaction between the organisms with a mind to prediction and description rather than control.

Since 1925 various contributions and technical developments have advanced the state of the art of water quality modeling. Particularly, the advent of the digital computer has expanded study beyond the limits experienced by Streeter and Phelps. One of the major influences from the modern sanitary engineering perspective is Robert Thomann, formerly technical director of the Delaware Estuary Comprehensive Study (DECS) and now a professor at Manhattan College. The program documented here, HARO3, is basically a representation of an approach developed by Thomann for the Delaware² which has proven itself to be particularly effective as a tool for water quality management.

As with Streeter and Phelps, the body of water is assumed to be at a steady state in time, and BOD and dissolved oxygen are the water quality variables (however, the program is general enough so that other variables such as temperature, coliform bacteria, etc. which are analogous to BOD and dissolved oxygen, could be modeled). Then the system is broken up into finite volumes which are completely mixed. By stipulating a priori the flow and dispersion across the interfaces between volumes, the hydrodynamics of the system are input to the model and by using mathematics the concentrations of the variables in each volume can be calculated. Thus the approach allows extension from streams to estuaries and lakes.

This report is in several parts. First, the theoretical background is developed. This is done in terms of an estuary since it is one of the more complex bodies of water to which this program can be applied. However, the concepts expressed can be readily applied to lakes, streams and other bodies of water. Then, a description of the computer program is given followed by a user's guide.

As a final note, HARO3 is meant to be used to either furnish insight into a particular phenomena, or as a predictive device for use in water quality planning. Care must be taken at all times to consider all the assumptions underlying its formulation and by no means could it ever be construed to apply to any and every aquatic system or problem. With this in mind it is an excellent tool for the use of those interested in applying rational approaches to the problems of the deterioration of the environment.

THEORY

T-1

One dimensional analysis of a single substance...

Thomann's approach 1,2 to steady-state estuarine water quality modeling essentially applies a numerical solution technique to a convective-diffusion equation for mass transport including decay and source terms. This equation, in time variable form for a one-dimensional channel of uniform cross-section, may be written as:

$$\frac{\partial c}{\partial t} + U \frac{\partial c}{\partial x} = E \frac{\partial^2 c}{\partial x^2} - kc + (\text{sources} - \text{sinks}) \dots\dots(T-1)$$

where

x=distance
t=time (on the scale of minutes to hours)
c=concentration of a constituent
E=longitudinal dispersion coefficient
U=tidal velocity
k=first order decay rate of constituent

A steady state in an estuary is a somewhat difficult concept to define. The term literally means that the constituent under investigation and the parameters which describe it do not vary in the time scale of the problem. As an estuary, in this report, is defined as a body of water subject to tidal oscillations, it can be argued that such a system will never reach a steady state but will continuously be in transition. Several investigators 3,4,5 have treated the subject and one approach is to take average values over a tidal cycle. The following relationship results:

$$\frac{\partial \bar{c}}{\partial t_t} + U_f \frac{\partial \bar{c}}{\partial x} = \bar{E} \frac{\partial^2 \bar{c}}{\partial x^2} - k\bar{c} + (\text{sources} - \text{sinks}) \dots\dots\dots(T-2)$$

where

the bar above a parameter or variable designates
that the value is averaged over a tidal cycle

U_f = net advective velocity. In many cases this can be interpreted as the velocity caused by fresh water flow entering the estuary
 t_t = time (on the scale of the time of a tidal cycle - several hours)
 $\bar{E}$ = a tidally averaged dispersion coefficient which includes the dispersive effect caused by tidal motion

A "steady state" for equation T-2 therefore means that the variables and parameters in question do not vary from tidal cycle to tidal cycle. This situation is often approximated in the summer and early fall when low rainfall minimizes the transients caused by fresh water runoff to an estuary and meteorological conditions are relatively constant. These periods are often critical when investigating such a classical gauge of pollution as dissolved oxygen.

With this as background, Thomann suggested that the system be divided into volumes or segments as in the one dimensional system depicted in figure T-1.

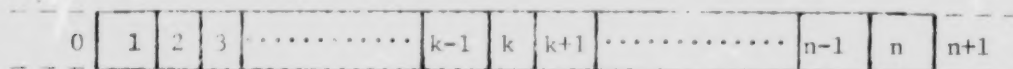


Figure T-1: Estuary of n segments

Equation T-2 can then be written in the following form for Section k (from this point on the bar which was used to designate that a parameter or variable was tidally average will be dropped for convenience):

$$\text{Vol}_k \frac{dc_k}{dt} + Q_{fk} l_k \frac{dc_k}{dx} = E_k A_k l_k \frac{d^2 c_k}{dx^2} - K_k \text{Vol}_k c_k + W_k \dots \dots \dots (T-3)$$

where

k = a subscript which denotes that the variable or parameter is an average for the segment k .

Q_{fk} = average net advective flow for the segment.

$$= U_{fk} A_k$$

Vol_k = volume of the segment = $A_k l_k$

A_k = cross-sectional area of the segment

l_k = length of the segment

W_k = waste input to the segment

At steady state c_k/t would equal zero and equation T-3 could be written as:

$$0 = E_k A_k l_k \frac{d^2 c_k}{dx^2} - Q_{fk} l_k \frac{dc_k}{dx} - K_k Vol_k c_k + W_k \dots \dots \dots (T-4)$$

Each term containing a differential in equation T-4 can be approximated mathematically, as:

$$E_k A_k l_k \frac{d^2 c_k}{dx^2} = E'_{k-1,k} (c_{k-1} - c_k) + E'_{k,k+1} (c_{k+1} - c_k) \dots \dots \dots (T-5)$$

$$Q_{fk} l_k \frac{dc_k}{dx} = Q_{k,k+1} (\alpha_{k,k+1} c_k + \beta_{k,k+1} c_{k+1}) - Q_{k-1,k} (\alpha_{k-1,k} c_{k-1} + \beta_{k-1,k} c_k) \dots (T-6)$$

where

$$E'_{ij} = E_{i,j} A_{i,j} / l_{i,j} \dots \dots \dots (T-6a)$$

i, j = subscript designating the interface between segments i and j .

$l_{i,j}$ = The average length of adjacent segments
 $= (l_i + l_j) / 2$

$\alpha_{i,j}$ and $\beta_{i,j}$ = weighting coefficients used to correct the approximations of equation T-6 for adjacent segments of unequal length.

$$\alpha_{i,j} = \frac{l_j}{l_i + l_j} \dots \dots \dots (T-7)$$

$$\beta_{i,j} = 1 - \alpha_{i,j} = \frac{l_j}{l_i + l_j} \dots \dots \dots (T-8)$$

As well, the above weighting coefficients can be used to insure meaningful results. It can be shown that for all positive solutions

$$\alpha - 1 - E'/Q \dots \dots \dots (T-8a)$$

It must be stated here that Thomann's approximation in equation T-5 is strictly correct for segments of equal length (and in two and three dimensions for orthogonally shaped segments). Therefore, care should be exercised to avoid the placement of segments of highly different lengths adjacent to each other or the construction of very irregularly shaped segments. In the event that this is unavoidable, adjustment of E may be necessary to reflect the true effect represented by equation T-5.

As well, it has been shown that a numerical dispersion effect is implicit in this particular difference scheme which can be estimated by

$$E_{\text{numerical}} = U l (\alpha - 1/2) \dots \dots \dots (T-8b)$$

This can be particularly significant in streams where velocities are high and distortion may result. It is therefore imperative that the modeller be always aware of the numerical dispersion in this model and make appropriate correction for it.

Equations T-5 and T-6 can be substituted into (T-4):

$$\begin{aligned}
 0 = & E'_{k-1,k} (c_{k-1} - c_k) + E'_{k,k+1} (c_{k+1} - c_k) \\
 & + Q_{k-1,k} (\alpha_{k-1,k} c_{k-1} + \beta_{k-1,k} c_k) \\
 & - Q_{k,k+1} (\alpha_{k,k+1} c_k + \beta_{k,k+1} c_{k+1}) \\
 & - K_k \text{Vol}_k c_k + W_k \dots \dots \dots (T-9)
 \end{aligned}$$

By grouping terms

$$\begin{aligned}
 & (-Q_{k-1,k} \alpha_{k-1,k} - E'_{k-1,k}) c_{k-1} \\
 & + (Q_{k,k+1} \alpha_{k,k+1} - Q_{k-1,k} \beta_{k-1,k} + E'_{k-1,k} + E'_{k,k+1} + \text{Vol}_k K_k) c_k \\
 & + (Q_{k,k+1} \beta_{k,k+1} - E'_{k,k+1}) c_{k+1} - W_k \dots \dots \dots (T-10)
 \end{aligned}$$

Letting

$$a_{k,k-1} = -Q_{k-1,k} \alpha_{k-1,k} - E'_{k-1,k} \dots \dots \dots (T-11)$$

$$a_{k,k} = Q_{k,k+1} \alpha_{k,k+1} - Q_{k-1,k} \beta_{k-1,k} + E'_{k-1,k} + E'_{k,k+1} + \text{Vol}_k K_k \dots (T-12)$$

$$a_{k,k+1} = Q_{k,k+1} \beta_{k,k+1} - E'_{k,k+1} \dots \dots \dots (T-13)$$

The general equation for the kth segment is therefore

$$a_{k,k-1} c_{k-1} + a_{k,k} c_k + a_{k,k+1} c_{k+1} = W_k \dots \dots \dots (T-14)$$

For the furthest upstream section (figure T-1, section 1), which is a boundary of the system, a similar procedure would yield:

$$a_{11} c_1 + a_{12} c_2 = W_1 + (Q_{01} \alpha_{01} + E'_{01}) c_o \dots \dots \dots (T-15)$$

or

$$a_{11} c_1 + a_{12} c_2 = W'_1 \dots \dots \dots (T-16)$$

where

o = a subscript to denote the values of the variables and parameters beyond the upstream boundary.

For the furthest downstream segment (in figure T-1, segment k):

$$a_{n-1,n} c_{n-1} + a_{n,n} c_n = W_n + (-Q_{n,n+1} \alpha_{n,n+1} + E'_{n,n+1}) c_{n+1} \dots \dots (T-17)$$

or

$$a_{n-1,n} c_{n-1} + a_{n,n} c_n = W'_n \dots \dots \dots (T-18)$$

where

$n + 1$ = a subscript to denote the values of the variables and parameters beyond the downstream boundary.

The complete set of equations for the system can be written as

$$\begin{array}{cccccccccccl}
 a_{11}c_1 + a_{12}c_2 + 0 + 0 + \cdot & \cdot & \cdot & + 0 & = & W_1 \\
 a_{21}c_1 + a_{22}c_2 + a_{23}c_3 + 0 + \cdot & \cdot & \cdot & + 0 & = & W_2 \\
 0 + a_{32}c_2 + a_{33}c_3 + a_{34}c_4 + \cdot & \cdot & \cdot & + 0 & = & W_3 \\
 \cdot & \cdot & \cdot & & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & & \cdot & \cdot & \cdot \\
 0 & 0 & 0 & + \cdot & \cdot & \cdot & + 0 + a_{n,n+1}c_{n+1} + a_{nn}c_n = & W_n
 \end{array}$$

..... (T-19)

At this point there are n equations with n unknowns. Solutions may be obtained either by solving the equations simultaneously or by writing T-19 in matrix form and inverting it. This latter technique is employed in HARO3. Equation T-19 in matrix form is

$$\begin{bmatrix}
 a_{11} & a_{12} & 0 & \cdot & \cdot & \cdot & \cdot & 0 \\
 a_{21} & a_{22} & a_{23} & 0 & \cdot & \cdot & \cdot & 0 \\
 0 & a_{32} & a_{33} & a_{34} & 0 & \cdot & \cdot & 0 \\
 \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\
 0 & \cdot & \cdot & \cdot & 0 & \cdot & \cdot & \cdot
 \end{bmatrix}
 \begin{bmatrix}
 c_1 \\
 c_2 \\
 c_3 \\
 \cdot \\
 \cdot \\
 \cdot \\
 c_n
 \end{bmatrix}
 =
 \begin{bmatrix}
 W_1 \\
 W_2 \\
 W_3 \\
 \cdot \\
 \cdot \\
 \cdot \\
 W_n
 \end{bmatrix}
 \quad (T-20)$$

or

$$[A] (c) = (W) \quad (T-21)$$

By inverting [A] a solution vector can be obtained:

$$(c) = [A]^{-1} (W) \quad (T-22)$$

Besides allowing solution of equation (T-21), equation T-22 offers an additional feature. The elements of the matrix $[A]^{-1}$, which is called the single system response matrix, represent the unit response of a particular section to the addition of a unit load to another section. For instance, the element a_{23} of $[A]^{-1}$ is the unit concentration response of section 2 to a unit input of waste into section 3. This is a particularly useful feature of Thomann's technique in that once a system response matrix is generated for a particular set of parameters, the effect of various load changes reflecting treatment strategies can be directly determined from this matrix. It, therefore, provides a quick technique for judging the trade-offs of various treatment alternatives.

One dimensional analysis of coupled substances...

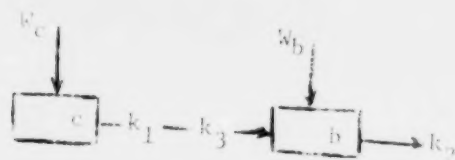


Figure T-2: Schematic for a coupled system of two reactants

Figure T-2 is a schematic for a coupled system of two constituents, c and b , which react with first order kinetics. W_c and W_b are waste inputs of the constituents and the k 's are the reaction rates which link them.

In classical sanitary engineering practice the BOD-dissolved oxygen system corresponds to the schematic with $c = \text{BOD}$ and $b = \text{dissolved oxygen deficit}$. The rate k_1 is referred to as the BOD removal rate, k_2 is a rate of reaeration from the atmosphere and k_3 is a deoxygenation rate. In the case where there is no loss of BOD via sedimentation or another non-oxygen demanding removal, k_1 would equal k_3 .

The equations describing the conservation of mass for c would be exactly like that developed in the previous section. The equation for b in a segment k at steady state would be

$$\begin{aligned}
 0 = & E'_{k-1,k} (b_{k-1} - b_k) + E'_{k,k+1} (b_{k+1} - b_k) \\
 & + Q_{k-1,k} (c_{k-1,k} b_{k-1} + c_{k-1,k} b_k) \\
 & - Q_{k,k+1} (c_{k,k+1} b_k + c_{k,k+1} b_{k+1}) \\
 & - Vol_k K_{k2} b_k + Vol_k K_{k3} c_k + W_b \dots \dots \dots (T-23)
 \end{aligned}$$

where

c_k = BOD in section k

b_k = dissolved oxygen deficit in section k

K_{k2} = reaeration rate in segment k

K_{k3} = deoxygenation rate in segment k

W_b = waste load or source of dissolved oxygen deficit to section k

T-21: By grouping terms this results in a matrix equation similar to

$$[B](b) = [Vol K_3](c) + (W_b) \dots \dots \dots (T-24)$$

where

$[Vol K_3]$ = an nxn diagonal matrix

$[B]$ = similar in form to $[A]$ with the exception that the diagonal elements contain the expression $Vol K_{k2}$ rather than $Vol K_{k1}$

(c) = solution vector to the single system (in this case BOD).

The solution is therefore

$$(b) = [B]^{-1}[Vol K_3](c) + [B]^{-1}(W_b) \dots \dots \dots (T-25)$$

In this program, three sources of dissolved oxygen deficit will be considered:

$$W_b = -PMR + BD*H + Y \dots \dots \dots (T-26)$$

where

PMR = the dissolved oxygen deficit due to the photosynthesis and respiration of algae.

BD*H = the dissolved oxygen deficit due to bottom deposits.

Y - direct oxygen deficit from waste sources

One additional feature of the analysis should be noted. By substituting equation T-22 into equation T-25 the following relationship results

$$(b) = [B]^{-1} (\text{Vol } K_3) [A]^{-1} (W_c) + [B]^{-1} (W_b) \dots \dots \dots (T-26a)$$

or after expressing the term $(\text{Vol } K_3)$ as a diagonal matrix and multiplying the matrixes the following results

$$(b) = [C]^{-1} (W_c) + [B]^{-1} (W_b) \dots \dots \dots (T-26b)$$

As can be seen $[C]^{-1}$ is a particularly useful entity in that it directly relates the deficit in the body of water to the waste load of BOD being discharged. It is called the total system response matrix.

Multi-dimensional analysis...

An extension of the previous analysis to more than one-dimension is relatively straightforward.



Figure T-3. schematic of generalized two dimensional system.

Figure T-3 illustrates a two dimensional system. Using the convention that flow entering a section is negative and flow out of a section is positive, an equation can be written representing the conservation of mass in segment i:

$$V_i \frac{dc_i}{dt} = 0 = \sum_k (-Q_{ik} c_k + Q_{ki} c_i) + E_{ik} (c_k - c_i) - V_i K_i C_i + W_i \quad \dots \quad (T-27)$$

It should be noted that the generalization of the advection term can be stated in this way due to the fact that

$$-Q_{ik} c_k = Q_{ki} c_i \quad \dots \quad (T-28)$$

$$\text{and } -Q_{ik} c_i = Q_{ki} c_k \quad \dots \quad (T-29)$$

(T-27) may be rewritten as

$$a_{ii} c_i + \sum_k a_{ik} c_k = W_i \quad (i=1,2,\dots,n) \quad \dots \quad (T-30)$$

where

$$a_{ii} = \frac{1}{V_i} (Q_{ik} c_k + E_{ik}) + V_i K_i \quad \dots \quad (T-31)$$

$$a_{ik} = Q_{ik} c_k - E_{ik} \quad \dots \quad (T-32)$$

For boundaries where flow enters the section with a concentration c_b :

$$a_{ii} = \sum_k (Q_{ik} c_{ik} + E'_{ik}) + V_i K_i + Q_{ii} c_{ii} + E'_{ii} \dots \dots \dots (T-33)$$

$$W_i = W_i + (E'_{ii} - Q_{ii} c_{ii}) c_b \dots \dots \dots (T-34)$$

For boundaries where flow leaves the section to an area with a concentration c_b :

$$a_{ii} = \sum_k (Q_{ik} c_{ik} + E'_{ik}) + V_i + Q_{ii} c_{ii} + E'_{ii} \dots \dots \dots (T-35)$$

$$W_i = W_i + (E'_{ii} - Q_{ii} c_{ii}) c_b \dots \dots \dots (T-36)$$

Similar to the previous analysis for one dimension, equation T-30 together with the appropriate boundary conditions can be incorporated into a matrix.

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & \dots & a_{nn} \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$

or $[A](c) = (W) \dots \dots \dots (T-37)$

with a solution

$$(c) = [A]^{-1}(W) \dots \dots \dots (T-38)$$

This may be extended to a coupled system of two reactants (e.g. BOD-DO deficit) in a fashion analogous to that done on page .

As well, the criterion that

$$\alpha > 1 - E/Q \dots \dots \dots (T-39)$$

to insure positive results also applies.

Application of the theory via a computer program...

At this point, the solution has been reduced to two equations: T-22 and T-26b for BOD and DO deficit, respectively.

$$(c) = [A]^{-1} (w_c) \dots \dots \dots (T-22)$$

$$(b) = [C]^{-1} (w_c) + [B]^{-1} (w_b) \dots \dots \dots (T-26b)$$

For HARO3, equation T-26b will not be used due to storage requirements for the additional matrix, [C].* In its place, a form of equation T-25 will be used

$$(b) = [B]^{-1} ((Vol * K_3) (c) + (w_b)) \dots \dots \dots (T-40)$$

Aside from input-output considerations, the major part of the algorithm of HARO3 therefore reduces to the setting up of the matrices [A] and [B] and their respective forcing functions.

Since the only difference between matrix [A] and matrix [B] is that their diagonals contain different reaction terms, a matrix excluding reaction terms can be formulated. Called the system matrix, [AB], it can be transformed into [A] or [B] by merely adding the appropriate reaction term to the diagonal.

* note: another version of the program will be available in the future which uses T-26b and which generates the valuable total system response matrix, [C]⁻¹.

With this as a background, a very simple representation of the major steps of HARO3 can be presented:

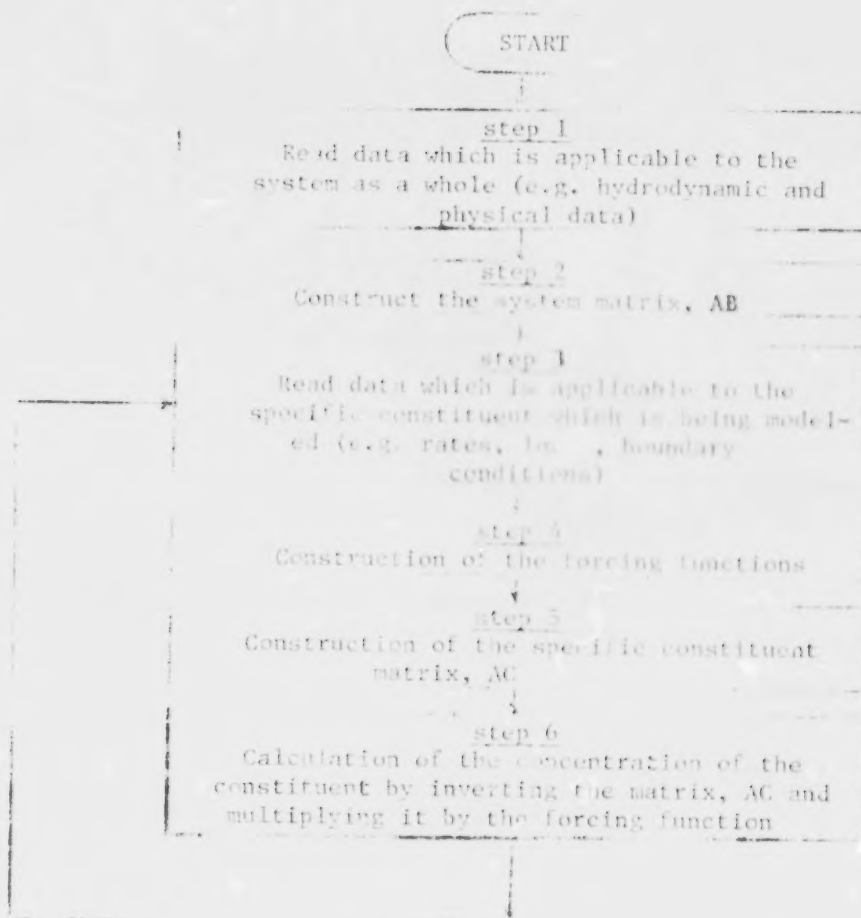


Figure T-4: Simple Schematic of HARO3 computer program

Of the six major parts, step 2 and step 4 require further discussion:

Step 2 - The construction of the system matrix [AB]

When constructing [AB], each section is considered individually with each of its interfaces treated one at a time. The following sequence is undertaken for each interface:

- 1) calculation of E' as in equation T-6a

$$E'_{ij} = \frac{E_{ij} A_{ij}}{(l_i + l_j) / 2} \dots \dots \dots (T-41)$$

- 2) a value of alpha is calculated to adjust the advective approximation for segments of unequal length.

for flow across the interface and into the section
($Q < 0$)

$$\alpha_{ij} = \frac{l_i}{l_i + l_j} \dots \dots \dots (T-42)$$

for flow across the interface and out of the section
($Q > 0$)

$$\alpha_{ij} = \frac{l_j}{l_i + l_j} \dots \dots \dots (T-43)$$

- 3) the criterion for positive solutions is applied to alpha (equation T-39) and if it is not met, an adjustment is made.

This is accomplished by the following test:

if $\alpha > 1 - E'/Q$ do not alter
if $\alpha < 1 - E'/Q$ recalculate α as

$$\alpha = 1 - E'/2Q \dots \dots \dots (T-44)$$

which places it well within the criterion.

3) calculation of the elements of the system matrix

The elements are calculated as in equation T-31 (excluding the reaction term) and T-32.

When each of these three steps is done for each interface, the procedure is repeated for each segment until all have been incorporated into the matrix.

Step 4 - The construction of the forcing function

At present, the forcing functions which are calculated are peculiar to the BOD - DO deficit system. From the theory, equations T-34 and T-36 give their most basic form:

$$\text{for } Q > 0 \quad W_i' = W_i + (E'_{ii} - Q_{ii} \beta_{ii}) c_b \quad (\text{T-36})$$

$$\text{for } Q < 0 \quad W_i' = W_i + (E'_{ii} - Q_{ii} \alpha_{ii}) c_b \quad (\text{T-34})$$

As can be seen, the forcing function consists of two basic parts:

1) Boundary condition forcing function

of the form, $[E'_{ii} - Q_{ii} (\alpha_{ii} \text{ or } \beta_{ii})] c_b$

where

E'_{ii} = the bulk dispersion across the interface between the section and the boundary.

Q_{ii} = the flow across that interface

α_{ii} or β_{ii} = assumed initially to be 0.5 and then subsequently tested as in equation T-39 and if necessary recalculated according to equation T-44.

c_b = the concentration across the boundary. Aside from this, this part of the forcing function does not vary as to the constituent being modeled.

2) Other forcing functions

of the form, W_i

for BOD or chlorides

W_i = any load to the section (e.g. waste loads, runoff loads, etc.)
for DO deficit

$$W_i = -DMR + BD\%H + \text{loads}$$

as explained in equation T-26.

THE COMPUTER PROGRAM

The computer program from which HAR03 evolved was developed by Hydrosience, Inc. for the Massachusetts Water Resources Commission¹. It was originally written for an IBM 1130 computer in FORTRAN IV and utilized a Gauss-Seidel technique to solve the set of simultaneous equations generated by the Thomann technique. The program was never adequately documented and as such was not appropriate for general distribution.

A source deck of the program was made available to the Environmental Protection Agency by the State of Massachusetts and after modification two new versions were published by E.P.A.² entitled HAR01 and HAR02. Compatible with an IBM 370 and an IBM 1130, respectively, these versions retained the Gauss-Seidel solution technique and had the advantage of being thoroughly documented.

The major difference between HAR03 and the previous versions is in its use of a matrix inversion solution technique. As well, parts of the algorithm have been redesigned to more accurately reflect Thomann's technique and to improve its clarity and ease of use.

In its present form HAR03 is programmed for an IBM 370/158 computer. The core requirements for each version have been summarized below:

<u>Version</u>	<u>Maximum No. of segments</u>	<u>Storage Requirements</u>
HAR50	50	76K
HAR100	100	148K
HAR200	200	410K

The compile and link time for any of these versions is .46 minutes, which includes optimization by the Fortran IV H Level compiler. Without optimization, compilation and linkage takes .24 minutes. Each of these versions are stored as load modules at OSI in Bethesda, Md. (EPA computer facility).

An estimate of the actual execution time is given in table C-1. Each time is for what is called an estuarine additive coupled system (described on page U-3) which analyzes the chlorides, carbonaceous and nitrogenous BOD and the D.O. deficit of a system. This type of run performs five matrix inversions which in larger systems takes up the largest amount of time.

<u>Number of segments</u>	<u>execution time (minutes)</u>
8	.02
30	.10
45	.27
64	.60

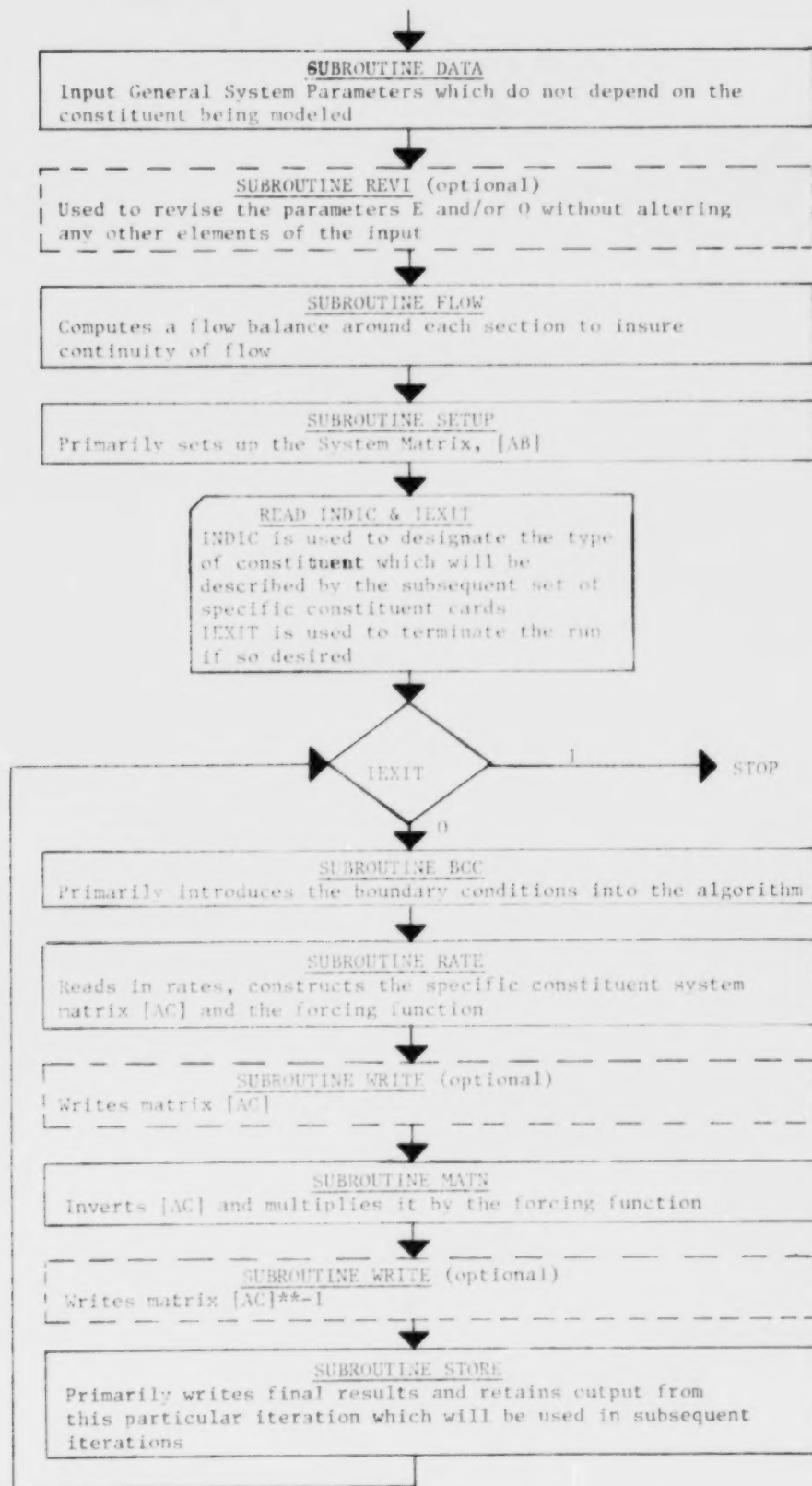


FIGURE C-1: Flow chart of the main program of HAR03
C-3

DESCRIPTION OF THE MAIN PROGRAM AND EACH OF THE SUBROUTINES

The Main Program-HAR03...

HAR03 has been programmed using a modular approach. Wherever possible, an attempt has been made to give each subroutine a unique function. The main program was designed to coordinate the subroutines to effectively analyze the water quality of a system. This coordination is depicted in figure C-1 which represents a development of the simple schematic given in figure T-3. In figure C-1 certain details have been omitted and if the user requires more detail he should consult the code itself.

Subroutine DATA...

The primary purpose of this subroutine is to input parameters which do not depend on the particular substance being modeled. These include system parameters (number of sections, indicators, etc.) and certain physical parameters such as cross-sectional area, net advective flow, etc., which are only input once when modeling a water body. These are in contrast to parameters such as loads and reaction rates which would vary with the constituent being modeled.

The particular tasks accomplished by DATA are:

- 1) read and write system parameters
- 2) initialize certain matrices to zero
- 3) read and write interface parameters AREA, E and Q and place them into the storage matrix ARRAY.
- 4) read and write the characteristic lengths (LA)
- 5) read the general section parameters depth (H), temperature (T), and volume (VOL)
- 6) Apply the following conversion factors:

$$Q(\text{MGD}) = Q(\text{CFS}) * .6463 \text{ MGD/cfs}$$

$$\text{VOL}(\text{MG}) = \text{VOL} (10^6 \text{ft}^3) * 7.48 \text{ gal/ft}^3$$

At this point, a further word about the function of ARRAY is in order. ARRAY is an N X 18 sized matrix which is used to save space when storing the interface parameters AREA, E and Q. Used in conjunction with IARRAY, ARRAY avoids the use of three N X N matrices when handling these variables. It does this as follows:

IARRAY(I,J)	contains the section number of the section which forms the interface with section I.
ARRAY(I,J)	contains the area of interface (I,IARRAY(I,J))
ARRAY(I,J + 1)	contains the E of interface (I,IARRAY(I,J))
ARRAY(I,J + 2)	contains the Q of interface (I,IARRAY(I,J))
J	is an integer variable which is incremented by 3 from 1 to 16

For computational purposes, every interface must be accounted for in terms of the section to which it applies. This would involve duplicate input - for instance, AREA (I,J) is the same as AREA (J,I). To simplify input, only one of the values must be input and subroutine DATA (statements DATA 075 to 091) fills out the remaining positions in ARRAY.

Subroutine REVI...

This subroutine is used to revise the parameters E and/or Q without altering any other elements of the input. This can often be an advantage when doing sensitivity analyses. The indicator ICON is employed to call the subroutine and designates which parameter is to be changed.

REVI also prints the revised values in a labelled tabular form.

Subroutine FLOW

FLOW basically computes a balance of the flows into and out of a section. If there is more or less than a **zero** balance around the section, the resultant value is printed as **an excess flow**.

The purpose of this exercise is to both keep track of flows and to insure that no mistakes were made when inputting the flow regime. This can be particularly useful when working in two or three dimensions.

Subroutine SETUP

The primary purpose of this subroutine is to set up the system matrix, AB, as was generally outlined on pages T-17 to T-18. The tasks performed by SETUP are:

- 1) calculation of the bulk dispersion coefficient, E'

According to the theory:

$$E'_{i,j} = \frac{E_{i,j} A_{i,j}}{l_{i,j}}$$

where

$E_{i,j}$ = the dispersion coefficient across the interface

$A_{i,j}$ = the cross-sectional area of the interface

$l_{i,j}$ = the average length of the adjoining
sections = $(l_i + l_j)/2$

The program calculates E' (EPRIM) as follows:

$$EPRIM(J) = ARRAY(I, JJ) * ARRAY(I, JJ+1) * 417.166 / (L(K, I) + L(I, K))$$

where

$$\text{ARRAY}(I, JJ) = A_{i,j} \text{ (ft}^2\text{)}$$

$$\text{ARRAY}(I, JJ+1) = E_{i,j} \text{ (mi}^2\text{/day)}$$

$$L(I, K) = I_i$$

$$L(K, I) = I_k$$

417.1166 - conversion factor which is computed as follows:

Original Units	Conversion Factor	New Units
$\frac{\text{ft}^2 \cdot \text{mile}^2}{\text{day} \cdot \text{ft}^2}$	$\frac{(5280 \text{ ft})^2}{(\text{mile})^2} \times \frac{7.481 \text{ gal}}{\text{ft}^3} \times 2 \times \frac{\text{MG}}{10^6 \text{ gal}}$	MGD
	417.1166	

- 2) A value of alpha is calculated to adjust the advective term for sections of different length. This value is checked against the positivity criterion (equation T-39) and if it is not met, alpha is recalculated (as in equation T-44)

$$\text{Alpha}(J) = 1.0 - (\text{EPRIM}(J) / (2 \cdot \text{ABS}(\text{ARRAY}(I, JJ+2))))$$

which corresponds to

$$\alpha = 1 - E'/20$$

- 3) The elements of the system matrix [AB] are calculated
- 4) The values for EPRIM and ALPHA are printed.
- 5) The section parameters: depth, volume and temperature, are printed.

Subroutine BCC

The primary purpose of this subroutine is to introduce boundary conditions into the algorithm. BCC marks the point at which the type of constituent being modeled becomes relevant. At the present time the program distinguishes between three types of constituents:

specific type in HAR03	which is analogous to
Chlorides	any conservative substance
BOD	a single constituent reacting with first order kinetics
D.O. deficit	the second constituent of a coupled, feed-forward system reacting with first order kinetics.

BCC performs the following tasks:

- 1) Reads the number of boundary conditions
- 2) If there are none it writes the message
ZERO BOUNDARY CONDITION
- 3) if there are boundary conditions it reads and writes
them with the appropriate labels (CL, BOD or DEF)
- 4) it calculates the part of the forcing function due
to the boundary condition as described on page

for $Q < 0$

$FRCBC(I) = 8.34 * BC(KLAST) * (EPRIM(J) - ALPHA(J) * ARRAY(I, JJ+2))$

for $Q > 0$

$FRCBC(I) = 8.34 * BC(KLAST) * (EPRIM(J) - (1.0 - ALPHA(J)) * ARRAY(I, JJ+2))$

where

FRCBC(1) = forcing function due to the boundary condition
BC = boundary concentration (mg/l)
EFRIM = E' (MGD)
ARRAY(1,JJ+2) = Q (MGD)
8.34 = conversion factor of (MGD*mg/l) to #/day

Subroutine RATE

RATE finishes preparation for calculation by completing the construction of the specific constituent system matrix [AC] and the appropriate forcing function. It does this by:

- 1) Reading the reaction rates (@ T=20° C) which are to be added to the diagonal of [AB] to transform it to [AC]. In the BOD-DO deficit system these rates are equal to
 - a) The removal rate, Kr or Kd, for CBOD and NBOD, respectively
 - b) the reaeration rate, Ka, for deficit
 - c) zero for chlorides

At the same time it inputs the appropriate temperature correction factors which are used to adjust the rates via the following general formula

$$K_t = K_{20} \cdot \theta^{(T-20)}$$

where some typical values are 3

rate	θ
Kr	1.047
Ka	1.024

- 2) the rates are multiplied by the section volumes and added to the diagonal of [AB] converting it to [AC]
- 3) for BOD or chlorides the forcing function is formed by reading the waste loads (LOAD) and adding them to FRCBC which was calculated in subroutine BCC

- 4) for D.O. deficit the forcing function is completed by first reading the deoxygenation rate (K_d) the benthic demand (BD) and the net photosynthesis effect (PMR). Appropriate temperature correction factors are read and applied to K_d and BD. The loads are read and then the forcing function is formed (as in equation)

$$XK1(I) = 8.34 * VOL(I) * (XK1(I) * KD(I) * FL - PMR(I) + BD(I) * H(I)) + Y(I)$$

where

XK1(I) on the left hand side of the equation is the deficit forcing function
 XK1(I) on the right hand side of the equation is the BOD concentration in the body of water as calculated during the BOD iteration.
 FL is a ratio relating ultimate to 5-day BOD
 Y is the same as FRCBC as calculated in subroutine BCC

then the deficit waste load is added.

$$XK1 = XK1 + LOAD$$

Subroutine WHITE

This subroutine writes the basic matrices before and after inversion if this is required.

Subroutine MATN

This subroutine inverts the matrix [AC] and multiplies it by the forcing function.

Subroutine STORE...

Subroutine STORE performs a number of miscellaneous tasks:

- 1) writes the final concentrations for each constituent being modeled
- 2) calculates the saturation value of oxygen ⁴

$$CS(I) = (1. - .000009 * CL(I)) * (14.652 - .41022 * T(I) + .0079910 * T(I) ** 2. - .000077774 * T(I) ** 3.)$$

where T(I) = the temperature of a section

CL(I) = the chloride concentration of the section

- 3) performs what can be called miscellaneous bookkeeping functions. For instance, it retains values of a particular constituent which would be necessary when calculating another constituent. (e.g. the BOD is an input to the calculation of DO deficit and therefore must be retained). It therefore plays an important **role** in the coordination of a particular configuration of reactants.

C*****		DATA 054
DO 1001 I=1,N		DATA 055
DO 1021 J=1,18		DATA 058
1021 ARRAY(I,J)=0.0		DATA 059
DO 1001 J=1,6		DATA 060
LA(I,J)=0.0		SEPT 74
1001 IARRAY(I,J)=0		DATA 061
C*****		DATA 062
C		*DATA 063
C READ AND WRITE INTERFACE PARAMETERS AREA, E AND Q AND PLACE		*DATA 064
C THEM INTO ARRAY		*DATA 065
C		*DATA 066
C*****		DATA 067
DO 1002 I=1,N		SEPT 74
READ(MX,1111) (AREA(J),E(J),Q(J), IARRAY(I,J),J=1,6)		DATA 069
DO 1002 J=1,6		SEPT 74
IF(AREA(J))72,71,72		SEPT 74
72 IF(IARRAY(I,J))74,74,71		SEPT 74
74 WRITE (NX,101)I,IARRAY(I,J)		SEPT 74
CALL EXIT		SEPT 74
71 JJ=(J-1)*3+1		SEPT 74
ARRAY(I,JJ)=AREA(J)*SCALE(1)		DATA 072
ARRAY(I,JJ+1)=E(J)*SCALE(2)		DATA 073
1002 ARRAY(I,JJ+2)=Q(J)*SCALE(3)		DATA 074
DO 1008 I=1,N		DATA 075
DO 1008 JJ=1,6		DATA 076
IF(IARRAY(I,JJ))1008,1008,1008		DATA 077
1008 IF(IARRAY(I,JJ)-I)1012,1008,1012		DATA 078
1012 JJJ=(JJ-1)*3+1		DATA 079
DO 1004 J=1,6		DATA 080
JK=(J-1)*3+1		DATA 081
NK=IARRAY(I,JJ)		DATA 082
IF(IARRAY(NK, J))1005,1006,1005		DATA 083
1006 ARRAY(NK, JK)=ARRAY(I,JJJ)		DATA 084
ARRAY(NK, JK+1)=ARRAY(I,JJJ+1)		DATA 085
ARRAY(NK, JK+2)=-ARRAY(I,JJJ+2)		DATA 086
IARRAY(NK, J)=I		DATA 087
GO TO 1008		DATA 088
1005 IF(IARRAY(NK, J)-I)1004,1008,1004		DATA 089
1004 CONTINUE		DATA 090
1008 CONTINUE		DATA 091
WRITE (NX,2200)		DATA 092
LINE=0		SEPT 74
DO 1032 I=1,N		DATA 093
WRITE(NX,3000) I,IARRAY(I,1),ARRAY(I,1),ARRAY(I,2),ARRAY(I,3),		DATA 094
1 I,IARRAY(I,2),ARRAY(I,4),ARRAY(I,5),ARRAY(I,6),		DATA 095
1 I,IARRAY(I,3),ARRAY(I,7),ARRAY(I,8),ARRAY(I,9)		DATA 096
WRITE(NX,3000) I,IARRAY(I,4),ARRAY(I,10),ARRAY(I,11),ARRAY(I,12),		DATA 097
1 I,IARRAY(I,5),ARRAY(I,13),ARRAY(I,14),ARRAY(I,15),		DATA 098
1 I,IARRAY(I,6),ARRAY(I,16),ARRAY(I,17),ARRAY(I,18)		DATA 099
LINE=LINE+2		SEPT 74
IF(FLOAT(LINE/54)-FLOAT(LINE)/54.)1032,1099,1099		SEPT 74
1099 WRITE(NX,2200)		SEPT 74
LINE=0		SEPT 74

```

1032 CONTINUE
C *****
C
C READ AND WRITE INTERFACE PARAMETER- CHARACTERISTIC LENGTH
C *****
C WRITE(NX,300)
C LINE=0
C DO 500 I=1,N
C READ(MX,201)(NLA(I,J),LA(I,J), J=1,6)
C DO 77 J=1,6
77 LA(I,J)=LA(I,J)*SCALE(4)
C WRITE(NX,200)(I,NLA(I,J),LA(I,J),J=1,6)
C LINE=LINE+1
C IF(FLOAT(LINE/54)-FLOAT(LINE)/54.)500,1098,1098
1098 WRITE(NX,300)
C LINE=0
C 500 CONTINUE
C *****
C
C READ SECTION PARAMETERS- DEPTH, VOLUME AND TEMPERATURE
C *****
C READ(MX,31)(P(I),I=1,N)
C READ(MX,31) (T(I),VOL(I),I=1,N)
C IF(T(2))14,13,14
13 DO 14 I=1,N
C T(I)=T(1)
14 CONTINUE
C *****
C
C APPLY CONVERSION FACTORS
C *****
C DO 12 I=1,N
C DO 23 J=1,6
C JJ=(J-1)*3+1
23 ARRAY(I,JJ+2)=ARRAY(I,JJ+2)*.6463
12 VOL(I)=VOL(I)*7.48
C RETURN
C END
C SUBROUTINE REVI
C *****
C *****
C
C SUBROUTINE REVI
C
C THIS SUBROUTINE CAN BE USED TO CHANGE THE PARAMETERS E AND/OR
C Q WITHOUT ALTERING THE REST OF THE INPUT
C *****
C *****
C REAL LA(100,6)
C DIMENSION Q(6),E(6),REVIS(12)

```

```

DATA 100
DATA 101
*DATA 102
*DATA 103
*DATA 104
DATA 105
DATA 106
SEPT 74
DATA 107
SEPT 74
SEPT 74
SEPT 74
SEPT 74
SEPT 74
SEPT 74
SEPT 74
DATA 118
DATA 119
*DATA 120
*DATA 121
*DATA 122
DATA 123
DATA 124
DATA 125
DATA 126
DATA 127
DATA 128
DATA 129
DATA 130
*DATA 131
DATA 132
*DATA 133
DATA 134
DATA 135
DATA 136
DATA 137
DATA 138
DATA 139
DATA 140
DATA 142
REVI 000
REVI 001
REVI 002
REVI 003
REVI 004
REVI 005
REVI 006
REVI 007
REVI 008
REVI 009
REVI 010
SEPT 74
REVI 011

```

COMMON/ALGAE/NX,N,INDIC,ICON,MMM,NMK	REVI 012
COMMON/BASS/MX,IPRNT,FRCBC(100)	SEPT 74
COMMON/CONCE/LA,SCALE(4),ARRAY(100,18),IARAY(100,6),NLA(100,6)	SEPT 74
2 FORMAT(1H1,40X'REVISED PARAMETER LIST'//)	REVI 014
5 FORMAT(12F5.0)	REVI 015
10 FORMAT(/50X,'NEW DISPERSIONS',/6X,5('INTERFACE',3X,'E',7X),'INTERREVI 016	
1FACE',3X,'E'/ 15X,5(	'(MREVI 017
7I**2/DAY)',9X) ,'(MI**2/DAY))'//)	REVI 018
13 FORMAT(3X,6(3X,I4,'-',I3,F9.3))	REVI 019
14 FORMAT(/50X'NEW FLOWS'/7X,6('INTERFACE',4X'Q',6X)/18X,5(' (CFS)',1REVI 020	
65X)', '(CFS))'//)	REVI 021
WRITE (NX,2)	REVI 022
GO TO(9,9),ICON	REVI 023
C*****	REVI 024
C	*REVI 025
C CHANGE E'S	*REVI 026
C	*REVI 027
C*****	REVI 028
8 DO 6 I=1,N	REVI 029
IF(I-(I/2)*2)21,21,20	REVI 030
20 READ(MX,5)REVIS	REVI 031
IPDS=0	REVI 032
21 DO 6 J=1,6	REVI 033
IPDS=IPDS+1	REVI 034
JJ=(J-1)*3+1	REVI 035
6 ARRAY(I,JJ+1)=REVIS(IPDS)*SCALE(2)	REVI 036
WRITE (NX,10)	REVI 037
DO 11 I=1, N	REVI 038
DO 12 J=1,6	REVI 039
JJ=(J-1)*3+1	REVI 040
12 F(J)=ARRAY(I,JJ+1)/SCALE(2)	REVI 041
11 WRITE (NX,13)(I, IARAY (I,J), E(J), J=1, 6)	REVI 042
GO TO 99	REVI 043
C*****	REVI 044
C	*REVI 045
C CHANGE Q'S	*REVI 046
C	*REVI 047
C*****	REVI 048
9 DO 4 I=1,N	REVI 049
IF(I-(I/2)*2)23,23,24	REVI 050
24 READ(MX,5)REVIS	REVI 051
IPDS=0	REVI 052
23 DO 4 J=1,6	REVI 053
IPDS=IPDS+1	REVI 054
JJ=(J-1)*3+1	REVI 055
4 ARRAY(I,JJ+2)=REVIS(IPDS)*SCALE(3)*0.6463	REVI 056
WRITE (NX,14)	REVI 057
DO 15 I=1, N	REVI 058
DO 16 J=1,6	REVI 059
JJ=(J-1)*3+1	REVI 060
16 Q(J)=ARRAY(I,JJ+2)/(SCALE(3)*0.6463)	REVI 061
15 WRITE (NX,13)(I, IARAY(I,J), Q(J), J=1, 6)	REVI 062
99 RETURN	REVI 063
END	REVI 064


```

DO 99 J=1,N
99 AB(I,J)=0.0
C *****
C
C      CALCULATE EPRIM AND ALPHA FOR EACH INTERFACE
C *****
      DO 20 J=1,6
      EPRIM(J)=0.0
      ALPHA(J)=0.0
      JJ=(J-1)*3+1
      K=IARRAY(I,J)
      IF(K)20,20,10
C *****
C
C      GENERATE (I,K) LENGTH ELEMENT
C *****
      10 DO 77 KK=1,6
      IF(NLA(I,KK)-K)77,81,77
      81 XLEN1=LA(I,KK)
      GO TO 82
      77 CONTINUE
C *****
C
C      GENERATE (K,I) LENGTH ELEMENT
C *****
      82 DO 78 KK=1,6
      IF(NLA(K,KK)-I)78,84,78
      84 XLEN2=LA(K,KK)
      GO TO 83
      78 CONTINUE
      83 EPRIM(J)=ARRAY(I,JJ)*ARRAY(I,JJ+1)*417.1166/(XLEN2+XLEN1)
      IF(ARRAY(I,JJ+2))300,301,301
      300 ALPHA(J)=XLEN1/(XLEN1+XLEN2)
      GO TO 200
      301 ALPHA(J)=XLEN2/(XLEN1+XLEN2)
      200 CONTINUE
      IF(ARRAY(I,JJ+2))14,17,14
      14 IF(ALPHA(J)-1.0+EPRIM(J)/ABS(ARRAY(I,JJ+2)))15,15,17
      15 ALPHA(J)=1.0-(EPRIM(J)/(2.*ABS(ARRAY(I,JJ+2))))
C *****
C
C      SETUP THE SYSTEM MATRIX - AB
C *****
      17 IF(ARRAY(I,JJ+2))18,19,19
      18 AB(I,I)=AB(I,I)+EPRIM(J)+((1.0-ALPHA(J))*ARRAY(I,JJ+2)
      IF(I-K)21,20,21
      21 AB(I,K)=ALPHA(J)*ARRAY(I,JJ+2) - EPRIM(J)
      GO TO 20
      19 AB(I,I)=AB(I,I)+ALPHA(J)*ARRAY(I,JJ+2)+ EPRIM(J)
      IF(I-K) 22,20,22

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22 AB(I,K)=(1.-ALPHA(J))*ARRAY(I,JJ+2)-EPRIM(J)          SETUP057
20 CONTINUE                                                SETUP058
C*****SETUP059
C                                                                *SETUP060
C      WRITE VALUES OF EPRIM AND ALPHA                    *SETUP061
C                                                                *SETUP062
C*****SETUP063
C      WRITE(NX,23)                                         SETUP064
C      1I,IARRAY(I,1),EPRIM(1),ALPHA(1),I,IARRAY(I,2),EPRIM(2),ALPHA(2), SETUP065
C      2I,IARRAY(I,3),EPRIM(3),ALPHA(3),I,IARRAY(I,4),EPRIM(4),ALPHA(4), SETUP066
C      2I,IARRAY(I,5),EPRIM(5),ALPHA(5),I,IARRAY(I,6),EPRIM(6),ALPHA(6)  SETUP067
C      LINE=LINE+1                                          SEPT 74
C      IF(FLOAT(LINE/54)-FLOAT(LINE)/54.)28,1028,1028      SEPT 74
1028 WRITE(NX,23)                                          SEPT 74
C      LINE=0                                              SEPT 74
C      28 CONTINUE                                         SETUP068
C*****SETUP069
C                                                                *SETUP070
C      WRITE SECTION PARAMETERS                             *SETUP071
C                                                                *SETUP072
C*****SETUP073
C      WRITE(NX,43)                                         SETUP074
C      LINE=0                                              SEPT 74
C      DO 399 I=1,N                                         SEPT 74
C      WRITE(NX,42) I,T(I),VOL(I),H(I)                     SEPT 74
C      LINE=LINE+1                                          SEPT 74
C      IF(FLOAT(LINE/54)-FLOAT(LINE)/54.)399,1029,1029    SEPT 74
1029 WRITE(NX,43)                                          SEPT 74
C      LINE=0                                              SEPT 74
C      399 CONTINUE                                         SEPT 74
C      DO 32 I=1,N                                         SETUP076
C      32 H(I)=3.281/H(I)                                   SETUP077
C      RETURN                                              SETUP078
C      END                                                SETUP079
C      SUBROUTINE RCC                                       RCC 000
C*****RCC 001
C*****RCC 002
C      SUBROUTINE RCC                                       RCC 003
C      BCC 004
C      BCC 005
C      THIS SUBROUTINE INCORPORATES BOUNDARY CONDITIONS INTO THE BCC 006
C      SYSTEM                                              BCC 007
C      BCC 008
C*****RCC 009
C*****RCC 010
C      REAL LA(100,6)                                       SEPT 74
C      DIMENSION ICOL(100),BC(100)                         BCC 012
C      COMMON/ALGAE/NX,N,INDIC,ICON,MMM,NMK                BCC 013
C      COMMON/BASS/NX,IPRNT,FRCHC(100)                     BCC 014
C      COMMON/BREAM/EPRIM(100),ALPHA(100)                  BCC 016
C      COMMON/COHOE/LA,SCALE(4),ARRAY(100,14),IARRAY(100,6),NLA(100,6) SEPT 74
C      7 FORMAT(I2)                                          BCC 017
C      44 FORMAT('1',40X,'ZERO BOUNDARY CONCENTRATIONS') BCC 018
C      209 FORMAT('1SEGMENT',5X,'CL BOUNDARY CONDITION(MG/L) ' BCC 019

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1	/ (14,19X,F10.2))	BCC	020
210	FORMAT('1SEGMENT',5X,'800 BOUNDARY CONDITION(MG/L) '	BCC	021
1	/ (14,19X,F10.2))	BCC	022
211	FORMAT('1SEGMENT',5X,'DEF BOUNDARY CONDITION(MG/L) '	BCC	023
1	/ (14,19X,F10.2))	BCC	024
1150	FORMAT(6(F8.0,14))	BCC	025
C	*****	BCC	026
C		*BCC	027
C	READ AND WRITE BOUNDARY CONDITIONS	*BCC	028
C		*BCC	029
C	*****	BCC	030
8	READ(MX,7)NUMBC	BCC	031
	IF(NUMBC)31,31,36	BCC	032
31	WRITE(NX,44)	BCC	033
	DO 103 I=1,50	BCC	034
	ICOL(I)=0	BCC	035
103	BC(I)=0.	BCC	036
	GO TO 213	BCC	037
36	READ(MX,1150)(BC(J), ICOL(J),J=1,NUMBC)	BCC	038
	IF(INDIC)206,207,208	BCC	039
206	WRITE(NX,209)(ICOL(J),BC(J), J=1,NUMBC)	BCC	040
	GO TO 213	BCC	041
207	WRITE(NX,210)(ICOL(J),BC(J), J=1,NUMBC)	BCC	042
	GO TO 213	BCC	043
208	WRITE(NX,211)(ICOL(J),BC(J), J=1,NUMBC)	BCC	044
C	*****	BCC	045
C		*BCC	046
C	CALCULATE THE PART OF THE FORCING FUNCTION DUE TO BOUNDARY COND.	*BCC	047
C		*BCC	048
C	*****	BCC	049
213	KLAST=1	BCC	050
	DO 60 I=1,N	BCC	051
	FRCBC(I)=0.0	BCC	052
	IF(ICOL(KLAST)-I)60,25,60	BCC	053
25	DO 30 J=1,6	BCC	054
	JJ=(J-1)*3+1	BCC	055
	K=IARAY(I,J)	SEPT	74
	IF(K-I) 30,35,30	SEPT	74
30	CONTINUE	BCC	058
C	*****	SEPT	74
C		SEPT	74
C	GENERATE (I,K) LENGTH ELEMENT	SEPT	74
C		SEPT	74
C	*****	SEPT	74
35	DO 77 KK=1,6	SEPT	74
	IF(NLA(I,KK)-K)77,81,77	SEPT	74
81	XLEN1=LA(I,KK)	SEPT	74
	GO TO 82	SEPT	74
77	CONTINUE	SEPT	74
C	*****	SEPT	74
C		SEPT	74
C	GENERATE (K,I) LENGTH ELEMENT	SEPT	74
C		SEPT	74
C	*****	SEPT	74

82 DO 78 KK=1,6	
IF(NLA(K,KK)-1) 78,84,73	SEPT 74
84 XLEN2=LA(K,KK)	SEPT 74
GO TO 83	SEPT 74
78 CONTINUE	SEPT 74
83 ALPHA(J)=0.5	SEPT 74
EPRIM(J)=ARRAY(I,JJ)*ARRAY(I,JJ+1)*417.1166/(XLEN2+XLEN1)	SEPT 74
IF(-0.5+EPRIM(J)/ABS(ARRAY(I,JJ+2))) 40,45,45	SEPT 74
40 ALPHA(J)=1.0-EPRIM(J)/(2.0*ABS(ARRAY(I,JJ+2)))	BCC 061
45 IF(ARRAY(I,JJ+2)) 50,55,55	BCC 062
50 FRCBC(I)=8.34*BC(KLAST)*(EPRIM(J)-ALPHA(J)*ARRAY(I,JJ+2))	BCC 063
KLAST=KLAST+1	BCC 064
GO TO 60	BCC 065
55 FRCBC(I)=8.34*BC(KLAST)*(EPRIM(J)-(1.0-ALPHA(J))*ARRAY(I,JJ+2))	BCC 066
KLAST=KLAST+1	BCC 067
60 CONTINUE	BCC 068
1000 RETURN	BCC 069
END	BCC 070
SUBROUTINE RATE	BCC 071
C*****	RATE 000
C*****	RATE 001
C	RATE 002
C	RATE 003
C	RATE 004
C	RATE 005
C THE PRIMARY PURPOSES OF THIS SUBROUTINE ARE TO CONSTRUCT THE	RATE 006
C SPECIFIC CONSTITUENT SYSTEM MATRIX, AC AND TO COMPLETE THE	RATE 007
C APPROPRIATE FORCING FUNCTIONS	RATE 008
C*****	RATE 009
C*****	RATE 010
REAL KA(100),KD(100),KSTOR(100),LOAD	RATE 011
DIMENSION Y(100),BD(100),PMR(100)	RATE 012
COMMON/ALGAE/NX,N,INDIC,ICON,MMH,NMK	RATE 013
COMMON/BASS/MX,IPRNT,FRCBC(100)	RATE 014
COMMON/PIKE/JCON,H(100),T(100),VOL(100),AB(100,100)	RATE 015
COMMON/ROUT/W(100),NK1(100),B(100,1),AC(100,100)	RATE 016
1 FORMAT(16F5.0)	RATE 017
12 FORMAT(F10.0,I3)	RATE 018
16 FORMAT(' BOD LOAD =',F10.0,' POUNDS/DAY FOR SECTION ',I3)	RATE 019
17 FORMAT(' DEF LOAD =',F10.0,' POUNDS/DAY FOR SECTION ',I3)	RATE 020
18 FORMAT('1')	RATE 021
34 FORMAT('1 SECTION CHLORIDE BOUNDARY LOAD (MGD*MG/L)')////	RATE 022
35 FORMAT(2X,I5,I2X,F14.2)	RATE 023
36 FORMAT('1 THE TEMPERATURE CORRECTION FACTOR FOR THE BOD REMOVAL	RATE 024
1 RATE =',F7.3,///,' SECTION BOD REM RATE BOD WASTE LOAD	RATE 025
1 BOUNDARY LOAD'/12X,'*TEMP CORR*',5X,'(MGD*MG/L)',7X,'(MGD*MG/L)')	RATE 026
37 FORMAT(2X,I5,F12.3,7X,F12.3,5X,F12.3)	RATE 027
38 FORMAT('1 THE TEMPERATURE CORRECTION FACTOR FOR THE REAERATION RATE	RATE 028
1 TE =',F7.3,/' THE BOD CORRECTION FACTOR (FL) =',F7.3,/' THE	RATE 029
1 TEMPERATURE CORRECTION FACTOR FOR THE BENTHAL DEMAND =',F7.3,/'	RATE 030
1 THE TEMP CORR FACTOR FOR KD =',F7.3,///' SECTION DEOX RATE	RATE 031
1 REAER RATE BOUND COND LOAD TOTAL LOAD PMR	RATE 032
1X,2('*TEMP CORR* ',2(' (MGD*MG/L)',4X),'MG/L/D *TEMP CORR*')	RATE 033
39 FORMAT(2X,I6,5X,F6.3,7X,F6.3,6X,F12.3,3X,F12.3,2X,F9.3,3X,F9.3)	RATE 034
	RATE 035

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C*****RATE 036
C
C READ IN DECAY RATE FOR BOD SYSTEM, REAERATION RATE FOR DO DEFICIT*RATE 037
C SYSTEM*RATE 038
C IF THE K'S ARE THE SAME FOR EVERY SECTION THEN JUST INPUT K(1) RATE 039
C READ AND APPLY TEMPERATURE CORRECTION FACTORS*RATE 040
C*RATE 041
C*****RATE 042
C IF(MMM-5)8,386,386*RATE 043
8 READ(MX,1)FAC1,(KA(I),I=1,15) RATE 044
IF(KA(2))202,3,202 RATE 045
3 DO 64 I=2,N RATE 046
64 KA(I)=KA(1) RATE 047
GO TO 334 RATE 048
202 LMM=N-15 RATE 049
IF(LMM)334,334,203 RATE 050
203 READ(MX,1) (KA(I),I=16,N) RATE 051
334 IF(MMM-3)2,388,2 RATE 052
388 DO 389 I=1,N RATE 053
389 KSTOR(I)=KA(I) RATE 054
FAC4=FAC1 RATE 055
GO TO 2 RATE 056
386 DO 387 I=1,N RATE 057
387 KA(I)=KSTOR(I) RATE 058
FAC1=FAC4 RATE 059
2 DO 6 I=1,N RATE 060
KA(I)=KA(I)*FAC1 ** (T(I)-20.) RATE 061
C*****RATE 062
C*****RATE 063
C CALCULATE THE SPECIFIC CONSTITUENT SYSTEM MATRIX, AC*RATE 064
C*RATE 065
C*****RATE 066
C DO 801 J=1,N RATE 067
801 AC(I,J)=AB(I,J) RATE 068
6 AC(I,I)=AB(I,I)+KA(I)*VOL(I) RATE 069
IF(INDIC)10,10,54 RATE 070
C*****RATE 071
C*****RATE 072
C CALCULATE THE BOD OR CHLORIDE FORCING FUNCTION*RATE 073
C*RATE 074
C*****RATE 075
C*****RATE 076
10 DO 9 I=1,N RATE 077
W(I)=FRCBC(I) RATE 078
9 FRCBC(I)=FRCBC(I)/8.34 RATE 079
LLL=0 RATE 080
1100 READ(MX,12)LOAD,ISEC RATE 081
IF(ISEC)13,22,13 RATE 082
13 IF(LLL)28,28,14 RATE 083
28 WRITE(NX,18) RATE 084
14 W(ISEC)=W(ISEC)+LOAD RATE 085
LLL=LLL+1 RATE 086
WRITE(NX,16)LOAD,ISEC RATE 087
GO TO 1100 RATE 088
C*****RATE 089

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C		*RATE 090
C	READ IN DEOXYGENATION RATE	*RATE 091
C	IF THE KD'S ARE THE SAME FOR EVERY SECTION THEN JUST INPUT KD(1)	*RATE 092
C		*RATE 093
C	READ IN PHOTOSYNTHESIS MINUS RESPIRATION(PMR), MG./L./DAY	*RATE 094
C	READ IN BOTTOM DEMAND(BD), GM./SQ. M./DAY	*RATE 095
C	VALUES MUST BE READ IN FOR EACH SECTION	*RATE 096
C	READ AND APPLY TEMPERATURE CORRECTION FACTORS	*RATE 097
C		*RATE 098
C	*****	*RATE 099
	54 READ(MX,1)FAC2,FL,(KD(J),J=1,14)	RATE 100
	DO 15 I=1,N	RATE 101
	Y(I)=FRCBC(I)	RATE 102
	15 FRCBC(I)=FRCBC(I)/8.34	RATE 103
	IF(KD(2))48,48,199	RATE 104
	48 DO 47 J=2,N	RATE 105
	47 KD(J)=KD(1)	RATE 106
	GO TO 19	RATE 107
	199 LII=N-14	RATE 108
	IF(LII)19,19,310	RATE 109
	310 READ(MX,1)(KD(I),I=15,N)	RATE 110
	19 IF(MMM-5)55,58,58	RATE 111
	55 READ(MX,1)(PMR(I),I=1,N)	RATE 112
	READ(MX,1)FAC3,(BD(I),I=1,N)	RATE 113
	DO 56 I=1,N	RATE 114
	56 BD(I)=BD(I)*FAC3 **((I(I)-20.)	RATE 115
	GO TO 57	RATE 116
	58 DO 53 I=1,N	RATE 117
	PMR(I)=0.	RATE 118
	53 BD(I)=0.	RATE 119
	57 DO 33 I=1,N	RATE 120
	KD(I)=KD(I)*FAC2 **((I(I)-20.)	RATE 121
C	*****	RATE 122
C		*RATE 123
C	READ AND WRITE LOADS	*RATE 124
C	CALCULATE THE DEFICIT FORGING FUNCTION	*RATE 125
C		*RATE 126
C	*****	RATE 127
	XK1(I)=8.34*VOL(I)*(XK1(I)*KD(I)*FL -PMR(I)+BD(I)*H(I))*Y(I)	RATE 128
	33 CONTINUE	RATE 129
	LLL=0	RATE 130
	101 READ(MX,12)LOAD,ISEC	RATE 131
	IF(ISEC)21,22,21	RATE 132
	21 IF(LLL)326,326,325	RATE 133
	326 WRITE(NX,18)	RATE 134
	325 XK1(ISEC)=XK1(ISEC)+LOAD	RATE 135
	LLL=LLL+1	RATE 136
	WRITE(NX,17)LOAD,ISEC	RATE 137
	GO TO 101	RATE 138
	22 IF(INDIC)29,30,31	RATE 139
	29 DO 303 I=1,N	RATE 140
	303 W(I)=W(I)/8.34	RATE 141
	WRITE(NX,34)	RATE 142
	WRITE(NX,35)(I,W(I),I=1,N)	RATE 143

GO TO 40	RATE 144
30 DO 304 I=1,N	RATE 145
304 W(I)=W(I)/8.34	RATE 146
WRITE(NX,36)FAC1	RATE 147
DO 853 I=1,N	RATE 148
853 W(I)=W(I)-FRCBC(I)	RATE 149
WRITE(NX,37)(I,KA(I),W(I),FRCBC(I),I=1,N)	RATE 150
DO 854 I=1,N	RATE 151
854 W(I)=FRCBC(I)+W(I)	RATE 152
GO TO 40	RATE 153
31 DO 305 I=1,N	RATE 154
305 XK1(I)=XK1(I)/8.34	RATE 155
WRITE(NX,38)FAC1,FL,FAC3,FAC2	RATE 156
WRITE(NX,39)(I,KD(I),KA(I),FRCBC(I),XK1(I),PMR(I),BD(I),I=1,N)	RATE 157
40 IF(INDIC)843,843,288	RATE 158
288 DO 842 I=1,N	RATE 159
842 W(I)=XK1(I)	RATE 160
843 DO 841 I=1,N	RATE 161
841 B(I,1)=W(I)	RATE 162
RETURN	RATE 163
END	RATE 164
SUBROUTINE WRITE	WRITE000
C*****	WRITE001
C*****	WRITE002
C	WRITE003
C	WRITE004
C	WRITE005
C THIS SUBROUTINE OUTPUTS MATRIX AC AND MATRIX AC**-1	WRITE006
C	WRITE007
C*****	WRITE008
C*****	WRITE009
COMMON/ALGAE/NX,N,INDIC,ICON,MMM,NMK	WRITE010
COMMON/TROUT/W(100),XK1(100),B(100,1),AC(100,100)	WRITE011
800 FORMAT('1',50X,'INITIAL SYSTEM MATRIX')	WRITE012
803 FORMAT(///48X,'INVERTED SYSTEM MATRIX')	WRITE013
1000 FORMAT(/4X,9I13/)	WRITE014
1005 FORMAT('1',51X,'INITIAL BOD MATRIX')	WRITE015
1007 FORMAT('1',48X,'INITIAL DO DEFICIT MATRIX')	WRITE016
1012 FORMAT(///50X,'INVERTED BOD MATRIX')	WRITE017
1015 FORMAT(///47X,'INVERTED DO DEFICIT MATRIX')	WRITE018
2000 FORMAT(13,1X,9E13.5/(4X,9E13.5))	WRITE019
JMAX=N	WRITE020
MM=1	WRITE021
IF(NMK)1003,1003,1010	WRITE022
1003 IF(INDIC)1018,1004,1006	WRITE023
1018 WRITE(NX,800)	WRITE024
GO TO 1008	WRITE025
1004 WRITE(NX,1005)	WRITE026
GO TO 1008	WRITE027
1006 WRITE(NX,1007)	WRITE028
1008 WRITE(NX,1000) (J,J=1,JMAX)	WRITE029
DO 1001 I=1,JMAX	WRITE030
1001 WRITE(NX,2000)I,(AC(I,J),J=1,JMAX)	WRITE031
NMK=NMK+1	WRITE032

RETURN	WRITE033
1010 IF(INDIC)1019,1011,1014	WRITE034
1019 WRITE(NX,803)	WRITE035
GO TO 1016	WRITE036
1011 WRITE(NX,1012)	WRITE037
GO TO 1016	WRITE038
1014 WRITE(NX,1015)	WRITE039
1016 WRITE(NX,1000) (J,J=1,JMAX)	WRITE040
DO 1002 I=1,JMAX	WRITE041
1002 WRITE(NX,2000)I,(AC(I,J),J=1,JMAX)	WRITE042
NMK=0	WRITE043
RETURN	WRITE044
END	WRITE045
SUBROUTINE MATN	MATN 000
C*****	MATN 001
C*****	MATN 002
C	MATN 003
C	MATN 004
C	MATN 005
C	MATN 006
C	MATN 007
C	MATN 008
C	MATN 009
C	MATN 010
C	MATN 011
C	MATN 012
C	MATN 013
C	MATN 014
C	MATN 015
C	MATN 016
C	MATN 017
C	MATN 018
C	SEPT 74
C	MATN 021
C	SEPT 74
C	MATN 023
C	MATN 024
C	MATN 025
C	SEPT 74
C	SEPT 74
C	SEPT 74
C	MATN 029
C	SEPT 74
C	MATN 031
C	MATN 032
C	SEPT 74
C	SEPT 74
C	MATN 035
C	MATN 036
C	SEPT 74
C	MATN 038
C	MATN 039
C	MATN 040
C	SEPT 74

150 DO 200 L=1,N	MATN 043
SWAP=AC(IROW,L)	SEPT 74
AC(IROW,L)=AC(ICOLU,L)	SEPT 74
200 AC(ICOLU,L)=SWAP	MATN 046
IF(MM)260, 260, 210	SEPT 74
210 DO 250 L=1, MM	MATN 048
SWAP=B(IROW,L)	SEPT 74
B(IROW,L)=B(ICOLU ,L)	SEPT 74
250 B(ICOLU ,L)=SWAP	MATN 051
260 INDEX(1,1)=IROW	MATN 052
INDEX(1,2)=ICOLU	SEPT 74
PIVOT(1)=AC(ICOLU,ICOLU)	SEPT 74
C	MATN 056
C	MATN 057
C	MATN 058
AC(ICOLU,ICOLU)=1.0	SEPT 74
DO 350 L=1,N	SEPT 74
350 AC(ICOLU,L)=AC(ICOLU,L)/PIVOT(1)	MATN 061
IF(MM)380, 380, 360	SEPT 74
360 DO 370 L=1,MM	MATN 063
370 B(ICOLU ,L)=B(ICOLU ,L)/PIVOT(1)	MATN 064
C	MATN 065
C	MATN 066
C	MATN 067
380 DO 550 L1=1,N	MATN 068
IF(L1-ICOLU) 400, 550, 400	SEPT 74
400 S=AC(L1,ICOLU)	MATN 070
AC(L1,ICOLU)=0.0	SEPT 74
DO 450 L=1,N	SEPT 74
450 AC(L1,L)=AC(L1,L)-AC(ICOLU,L)*S	MATN 073
IF(MM)550, 550, 460	SEPT 74
460 DO 500 L=1,MM	MATN 075
500 B(L1,L)=B(L1,L)-B(ICOLU ,L)*S	MATN 076
550 CONTINUE	MATN 077
C	MATN 078
C	MATN 079
C	MATN 080
DO 710 I=1,N	SEPT 74
L=N+1-I	SEPT 74
IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630	SEPT 74
630 JROW=INDEX(L,1)	MATN 084
JCOLU =INDEX(L,2)	SEPT 74
DO 705 M=1,N	SEPT 74
SWAP=AC(M,JROW)	SEPT 74
AC(M,JROW)=AC(M,JCOLU)	SEPT 74
AC(M,JCOLU)=SWAP	SEPT 74
705 CONTINUE	MATN 090
710 CONTINUE	MATN 091
740 CONTINUE	MATN 092
DO 901 I=1,N	MATN 094
DO 901 J=1,N	MATN 095
901 AC(I,J)=AC(I,J)/1000000.	MATN 096
RETURN	MATN 097
END	MATN 098

150	DO 200 L=1,N	MATN 043
	SWAP=AC(IROW,L)	SEPT 74
	AC(IROW,L)=AC(ICOLU,L)	SEPT 74
200	AC(ICOLU,L)=SWAP	MATN 046
	IF(MM)260, 260, 210	SEPT 74
210	DO 250 L=1, MM	MATN 048
	SWAP=B(IROW,L)	SEPT 74
	B(IROW,L)=B(ICOLU ,L)	SEPT 74
250	B(ICOLU ,L)=SWAP	MATN 051
260	INDEX(1,1)=IROW	MATN 052
	INDEX(1,2)=ICOLU	SEPT 74
	PIVOT(1)=AC(ICOLU,ICOLU)	SEPT 74
C		MATN 056
C	DIVIDE PIVOT ROW BY PIVOT ELEMENT	MATN 057
C		MATN 058
	AC(ICOLU,ICOLU)=1.0	SEPT 74
	DO 350 L=1,N	SEPT 74
350	AC(ICOLU,L)=AC(ICOLU,L)/PIVOT(1)	MATN 061
	IF(MM)380, 380, 360	SEPT 74
360	DO 370 L=1,MM	MATN 063
370	B(ICOLU ,L)=B(ICOLU ,L)/PIVOT(1)	MATN 064
C		MATN 065
C	REDUCE NON-PIVOT ROWS	MATN 066
C		MATN 067
380	DO 550 LI=1,N	MATN 068
	IF(LI-ICOLU) 400, 550, 400	SEPT 74
400	S=AC(LI,ICOLU)	MATN 070
	AC(LI,ICOLU)=0.0	SEPT 74
	DO 450 L=1,N	SEPT 74
450	AC(LI,L)=AC(LI,L)-AC(ICOLU,L)*S	MATN 073
	IF(MM)550, 550, 460	SEPT 74
460	DO 500 L=1,MM	MATN 075
500	B(LI,L)=B(LI,L)-B(ICOLU ,L)*S	MATN 076
550	CONTINUE	MATN 077
C		MATN 078
C	INTERCHANGE COLUMNS	MATN 079
C		MATN 080
	DO 710 I=1,N	SEPT 74
	L=N+1-I	SEPT 74
	IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630	SEPT 74
630	JROW=INDEX(L,1)	MATN 084
	JCOLU =INDEX(L,2)	SEPT 74
	DO 705 M=1,N	SEPT 74
	SWAP=AC(M,JROW)	SEPT 74
	AC(M,JROW)=AC(M,JCOLU)	SEPT 74
	AC(M,JCOLU)=SWAP	SEPT 74
705	CONTINUE	MATN 090
710	CONTINUE	MATN 091
740	CONTINUE	MATN 092
	DO 901 I=1,N	MATN 094
	DO 901 J=1,N	MATN 095
901	AC(I,J)=AC(I,J)/1000000.	MATN 096
	RETURN	MATN 097
	END	MATN 098

SUBROUTINE STORE		STORE000
C*****		STORE001
C*****		STORE002
C		STORE003
C	SUBROUTINE STORE	STORE004
C		STORE005
C*****		STORE006
C*****		STORE007
	DIMENSION CL(100),CS(100),R(100)	STORE008
	COMMON/ALGAE/NX,N,INDIC,ICON,MMM,NMK	STORE009
	COMMON/PIKE/JCON,H(100),T(100),VOL(100),AB(100,100)	STORE010
	COMMON/TROUT/W(100),XK1(100),B(100,1),AC(100,100)	STORE011
42	FORMAT('1 SECTION DEFICIT(MG/L)')	STORE012
44	FORMAT('1 SECTION BOD(MG/L)')	STORE013
45	FORMAT('1 SECTION CHLORIDES(MG/L)')	STORE014
48	FORMAT(3X,14,3X,F14.3)	STORE015
807	FORMAT(10X,13,5(4X,F9.2))	STORE016
808	FORMAT('1 SECTION CHLORIDES TEMPERATURE DEFICIT	STORE017
	1SATURATION DO',//)	STORE018
817	FORMAT('1', ' RESULTS FOR COMBINED (CARBONACEOUS	STORE019
	4S AND NITROGENOUS) RUN'//)	STORE020
828	FORMAT(' SECTION CHLORIDES TEMPERATURE DEFICIT	STORE021
	1SATURATION DO',/,19X,'(MG/L) (C) (MG/L)	SEPT 74
	1 (MG/L) (MG/L)')	SEPT 74
	DO 805 I=1,N	STORE023
805	XK1(I)=B(I,1)	STORE024
C*****		STORE025
C		STORE026
C	WRITES FINAL CONCENTRATIONS	STORE027
C		STORE028
C*****		STORE029
	11 IF(INDIC)850,840,41	STORE030
850	WRITE(NX,45)	STORE031
	GO TO 643	STORE032
840	WRITE(NX,44)	STORE033
	GO TO 643	STORE034
41	WRITE(NX,42)	STORE035
643	WRITE(NX,48)(I,XK1(I),I=1,N)	STORE036
9999	GO TO(1800,1801,1802,1801,1803),MMM	STORE037
1800	GO TO(1199,1199,813,813),JCON	STORE038
C*****		STORE039
C		STORE040
C	CALCULATES THE SATURATION VALUE OF DO	STORE041
C		STORE042
C*****		STORE043
	813 DO 815 I=1,N	STORE044
	CL(I)=XK1(I)	STORE045
815	CS(I)=(1.-.000009*CL(I))*(14.652-.41022*T(I)+.0079910*	STORE046
	1T(I)**2.-.000077774*T(I)**3.)	STORE047
	MMM=MMM+1	STORE048
	RETURN	STORE049
1199	DO 1139 I=1,N	STORE050
	CL(I)=0.	STORE051
1139	CS(I)=(1.-.000009*CL(I))*(14.652-.41022*T(I)+.0079910*	STORE052

```

      1T(I)**2.-.000077774*T(I)**3.)
      MMM=MMM+2
      RETURN
1801  MMM=MMM+1
      RETURN
1802  WRITE(NX,808)
      DO 806 I=1,N
      W(I)=CS(I)-XK1(I)
      WRITE(NX,807)I,CL(I),T(I),XK1(I),CS(I),W(I)
      806 CONTINUE
      GO TO(93,1804,93,1804),JCON
      93 RETURN
1804  DO 829 I=1,N
      829 R(I)=XK1(I)
      MMM=MMM+1
      RETURN
1803  WRITE(NX,817)
      WRITE(NX,828)
      DO 881 I=1,N
      XK1(I)=XK1(I)+R(I)
      W(I)=CS(I)-XK1(I)
      WRITE(NX,807)I,CL(I),T(I),XK1(I),CS(I),W(I)
      881 CONTINUE
      RETURN
      END

```

/*

```

STORE053
STORE054
STORE055
STORE056
STORE057
STORE058
STORE059
STORE060
STORE061
STORE062
STORE063
STORE064
STORE065
STORE066
STORE067
STORE068
STORE069
STORE070
STORE071
STORE072
STORE073
STORE074
STORE075
STORE076
STORE077

```

1950'S MANUAL

The manner in which the data deck for HARO3 is structured is shown in figure U-1. As can be seen, the cards can be divided into two basic groups:

- 1) General System Cards (GS cards) which are the same for any constituent or substance being modeled and need only be input once. They primarily contain the physical and hydrodynamic parameters of the system.
- 2) Specific Constituent Cards (SC cards) which as the name implies, are specific to the particular constituent being modeled. These include boundary concentrations and biological or chemical parameters such as rates and loads.

After reading the single set of GS cards, a variable number of sets of SC cards are read depending on the particular combination of reactions of the constituents being modeled. Two indicators are used to designate which combination is to be modeled:

- 1) INDIC: As can be seen from figure U-1, this indicator is read in prior to each set of SC cards. It can presently take on three values, -1, 0 and 1 to designate chlorides, BOD and DO deficit respectively
- 2) JCON: This indicator is read on the first GS card: the Title Card. It designates a particular combination or configuration of reactions and is utilized by subroutine STORE to direct the flow of the program.

Since HARO3 has been designed with the BOD-DO deficit system in mind, it is capable of handling reaction configurations which are to some extent peculiar to that system. However, it should be noted that there are many substances which are analagous to BOD and dissolved oxygen and can therefore be modeled using HARO3. With this in mind, the following are the particular combinations of reactants which can be presently modeled using the program:

- 1) Conservative substances: (Chlorides; total dissolved solids; some pesticides and herbicides; etc) any substance which does not decay or can be approximated by zero decay.
- 2) Single reactive substance: (BOD; coliform bacteria, ammonia; etc) any substance which decays according to first order kinetics
- 3) Coupled reactive substances: (BOD-DO deficit; polyphosphate - orthophosphate; ammonia-nitrate). A feed forward system of two substances reacting with first order kinetics.

- 4) Additive coupled substances: (CBOD, NBOD-DO deficit) this is peculiar to the BOD-DO deficit system where the BOD can be broken down into carbonaceous (CBOD) and nitrogenous (NBOD) components. Both components deplete dissolved oxygen but at different rates so each is computed separately and their deficits added to determine the total deficit.
- 5) Estuarine coupled reactive substances (Chlorides, BOD-deficit) HARO3 has the additional option for those estuaries where chlorides have been modeled. A chloride run can precede the BOD-deficit so that the resulting chloride concentrations can be used to determine the saturation value of dissolved oxygen.
- 6) Estuarine additive coupled system (Chlorides, BOD, CBOD-deficit). The same as 5 but for the additive system.

Figure H-2 summarizes the various deck setups for each of the above combinations with the appropriate values of IODIC and JODN.

A description of input and output is then followed by an example problem including sample input and output to further clarify the procedure.

Finally, some restrictions on the use of the program are given.

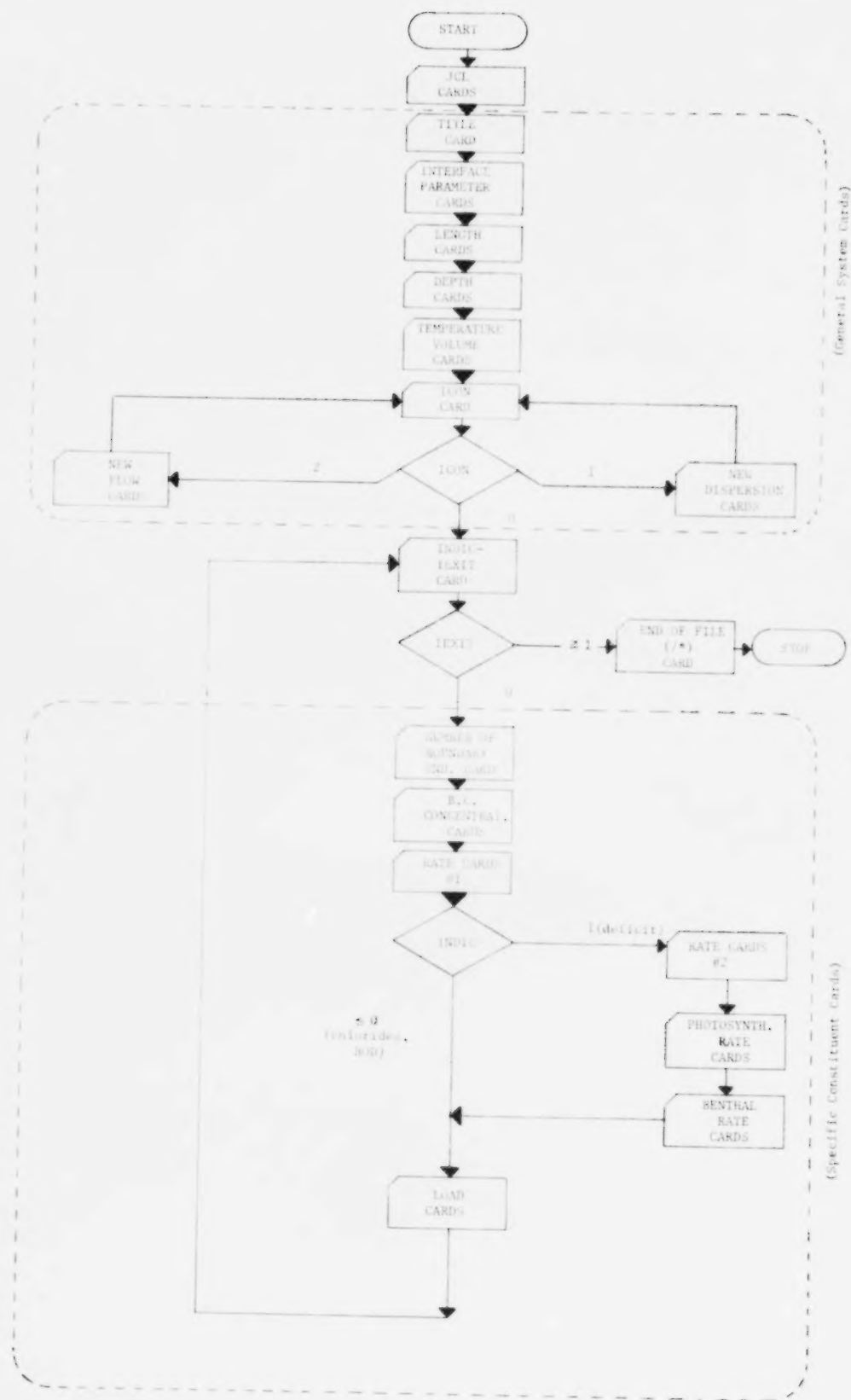


Figure U-1: Structure of data deck for RAR03



Figure U-2 : Deck setups for various combinations of reactants using program HARD3.

GENERAL SYSTEM CARDS

[TITLE CARD]

<u>Columns</u>	<u>Variable</u>	<u>Description</u>	<u>Units</u>	<u>Format</u>
(1-40)	TITLE	To be used to label the run		A40
(41-43)	N	The number of sections in the model		I3
(44-46)	IPRNT	An indicator, IPRNT=1 for printout of matrices IPRNT=0 to suppress the printout of matrices		I3
(47-49)	JCON	An indicator used to designate the type of system being modeled JCON=1 BOD Deficit JCON=2 CBOD NBOD Deficit JCON=3 Chlorides BOD Deficit JCON=4 Chlorides CBOD NBOD Deficit		I3
(53-59)	SCALE(1)	Area scale factor	ft ² /ou*	F7
(60-66)	SCALE(2)	Dispersion scale factor	mi ² /day/ou	F7
(67-73)	SCALE(3)	Flow scale factor	cfs/ou	F7
(74-80)	SCALE(4)	Length scale factor	ft/ou	F7

*note: ou stands for the "original units" in which the parameter to be converted by the scale factor is expressed. The purpose of the scale factors is to allow the user to input parameters in units which are different from those specified on the following pages. For instance, according to this program length should be input as feet. However, it may be more convenient to enter it in miles and set SCALE(4) to 5280. The program would then internally convert the length from miles to feet.

[INTERFACE PARAMETER CARDS (2 per section; total number = 2*N)]

<u>Columns</u>	<u>Variable</u>	<u>Description</u>	<u>Units</u>	<u>Format</u>
(1-6)	AREA	Cross sectional area of interface with section	ft ²	F6
(7-12)	E	Dispersion coefficient of first interface with section	mi ² /day	F6
(13-18)	Q	Flow * across the first interface with section	cfs	F6
(19-21)	IARAY	Section forming the first interface with section		I3
(22-27)	AREA	Cross sectional area of second interface	ft ²	F6
(28-33)	E	Dispersion coefficient of second interface	mi ² /day	F6
(34-39)	Q	Flow across the second interface	cfs	F6
(40-42)	IARAY	Section forming the second interface		I3
(43-48)	AREA	Cross sectional area of third interface	ft ²	F6
(49-54)	E	Dispersion coefficient of third interface	mi ² /day	F6
(55-60)	Q	Flow across the third interface	cfs	F6
(61-63)	IARAY	Section forming the third interface		I3

(note: The second interface parameter card is identical to above, but for the fourth, fifth and sixth interfaces. If the section in question has an interface which forms a boundary across which mass is transported (that is, a boundary condition) interface parameters must be input for it. To do this, input the appropriate AREA, E and Q for the interface and input the section's number as the IARAY.

It is only necessary to input the parameters for a particular interface once. In other words after inputting the parameters of the interface of section 1 with section 2, it is not necessary to input the parameters of the interface of section 2 with section 1.)

* flow out of a section is positive; flow into a section is negative.

[CHARACTERISTIC LENGTHS](1 card per section; 1 length for each interface; therefore up to 6 lengths per card)

<u>Columns</u>	<u>Variable</u>	<u>Description</u>	<u>Units</u>	<u>Format</u>
1-3	J1	First section which forms an interface with section 1		I3
4-13	LA(1,J1)	Length of section 1 with respect to section J1*	feet	F10
14-16	JJ	Second section which forms an interface with section 1.		I3
17-26	LA(1,JJ)	Length of section 1 with respect to section JJ	feet	F10
27-29	JK	Third section which forms an interface with section 1		I3
30-39	LA(1,JK)	Length of section 1 with respect to section JK	feet	F10
40-42	JL	Fourth section which forms an interface with section 1		I3
43-52	LA(1,JL)	Length of section 1 with respect to section JL	feet	F10
53-55	JM	Fifth section which forms an interface with section 1		I3
56-65	LA(1,JM)	Length of section 1 with respect to section JM	feet	F10
66-68	JN	Sixth section which forms an interface with section 1		I3
69-78	LA(1,JN)	Length of section 1 with respect to section JN	feet	F10

* note: the following figure illustrates the interpretation of characteristic lengths as used in this program.



figure U-1: Depiction of characteristic lengths

where

- ① - LA(I,JK) and LA(I,JI)
- ② - LA(I,JJ), LA(I,JM) LA(I,JL) and LA(I,JN)

As can be seen, any other than orthogonally shaped segments would present a problem as to the measurement of LA. It is therefore reiterated that oddly shaped segmentation schemes should be avoided except when absolutely necessary to depict the natural geometry of the system.

[DEPTH CARDS]

<u>Columns</u>	<u>Variable</u>	<u>Description</u>	<u>Units</u>	<u>Format</u>
1-10	H(1)	Depth of 1st section	ft	F10
11-20	H(2)	Depth of 2nd section	ft	F10
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	H(N)	Depth of Nth section	ft	F10

[TEMPERATURE-VOLUME CARDS]

1-10	T(1)	Water temperature of 1st section	°C	F10
11-20	VOL(1)	Volume of 1st section	10 ⁶ ft ³	F10
21-30	T(2)	Temperature of 2nd section	°C	F10
31-40	VOL(2)	Volume of 2nd section	10 ⁶ ft ³	F10
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	T(N)	Temperature of Nth section	°C	F10
-	VOL(N)	Volume of Nth section	10 ⁶ ft ³	F10

[ICON CARD]

<u>Columns</u>	<u>Variable</u>	<u>Description</u>	<u>Units</u>	<u>Format</u>
(1-2)	ICON	An indicator. If desired at this point changes in the E's or Q's which were read in previously, may be made using ICON If ICON=0: No changes are called for and the program would continue by reading the INDIC card as described on page U-11 If ICON=1: Would allow a new set of dispersion coefficients to be read as on "New E cards" (see below) If ICON=2: Would allow a new set of flows to be read as described on page U-11 (new Q Cards")		I2

[NEW E CARDS (OPTIONAL-MUST BE PRECEDED BY ICON CARD=1)]

<u>Columns</u>	<u>Variable</u>	<u>Description</u>	<u>Units</u>	<u>Format</u>
(1-5)	Revised E's	For 1st Interface with first section	M_1^2/day	F5
(6-10)	"	" 2nd " " " "	"	"
(11-15)	"	" 3rd " " " "	"	"
(16-20)	"	" 4th " " " "	"	"
(21-25)	"	" 5th " " " "	"	"
(26-30)	"	" 6th " " " "	"	"
(31-35)	"	" 1st " " second	"	"
(36-40)	"	" 2nd " " " "	"	"
(41-45)	"	" 3rd " " " "	"	"
(46-50)	"	" 4th " " " "	"	"
(51-55)	"	" 5th " " " "	"	"
(56-60)	"	" 6th " " " "	"	"

IN SIMILAR FASHION, REVISIONS ARE INPUTTED FOR THE THIRD TO Nth SECTIONS

note: These cards must be followed by another "ICON CARD" (as explained above). If revisions are to be made in flow, ICON must equal 2, and the new values can be read as on page U-11. If no more revisions are necessary, ICON must equal 0 and the program will proceed to read the "INDIC CARD" as explained on page U-11.

[NEW Q CARDS (OPTIONAL-MUST BE PRECEDED BY ICON CARD=2)] *

Columns	Variable	Description	Units	Format
(1-5)	Revised Q's	For 1st Interface with First Section	cfs	F5
(6-10)	"	" 2nd " " " "	"	"
(11-15)	"	" 3rd " " " "	"	"
(16-20)	"	" 4th " " " "	"	"
(21-25)	"	" 5th " " " "	"	"
(26-30)	"	" 6th " " " "	"	"
(31-35)	"	" 1st " " Second "	"	"
(36-40)	"	" 2nd " " " "	"	"
(41-45)	"	" 3rd " " " "	"	"
(46-50)	"	" 4th " " " "	"	"
(51-55)	"	" 5th " " " "	"	"
(56-60)	"	" 6th " " " "	"	"

IN SIMILAR FASHION, REVISIONS ARE INPUTTED FOR THE THIRD TO Nth SECTIONS

These cards must be followed by another "ICON CARD" (as explained on page U-4). If revisions are to be made in dispersion, ICON must equal 1 and the new values can be read as described on page U-4. If no more revisions are necessary, ICON must equal 0 and the program will proceed to read the "INDIC CARD" as explained below.

[INDIC CARD]

Columns	Variable	Description	Units	Format
(1-2)	INDIC	An indicator used to denote whether subsequent DATA will be for Chloride, BOD or D.O. deficit INDIC = 1 for Chloride INDIC = 0 for BOD INDIC = 1 for D.O. deficit		12
(3-4)	IEEXIT	An indicator which can either continue or terminate the run If IEEXIT>0 The run will Terminate IEEXIT≤0 The run will Continue		12

* on both the "Dev E Cards" and the "New Q Cards" the scale factors input on the title card (page U-6) apply.

SPECIFIC CONSTITUENT CARDS

[NUMBER OF BOUNDARY CONDITIONS]

Columns	Variable	Description	Units	Format
(1-2)	NUMBC	Number of boundary interfaces across which mass is transported		12

[BOUNDARY CONDITIONS]

(1-8)	BC(1)	Concentration of water quality parameter at first boundary	mg/l	F8
(9-12)	ICOL(1)	Section adjoining first boundary		14
	BC(2)	Concentration of water quality parameter at second boundary	mg/l	F8
	ICOL(2)	Section adjoining second boundary		14
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
(61-68)	BC(6)	Concentration of water quality parameter at 6th boundary	mg/l	F8
(69-72)	ICOL(6)	Section adjoining 6th boundary		14

Proceed with cards until a total of NUMBC boundary conditions have been read

[RATE CARD #1]***

(1-5)	FAC1	Temperature correction factor for first reaction rate	1/day	F5
(6-10)	K(1)*	First reaction rate for first section ** 1/day for Chlorides =0.9 for CBOD =CBOD removal rate(Kr) for NBOD =NBOD removal rate(Kn) for D.O. deficit =Reaeration rate	1/day	F5
	K(2)	First reaction rate for second section	1/day	F5
	-	-	-	-
	-	-	-	-
	-	-	-	-
(76-80)	K(15)	First reaction rate for Nth section	1/day	F5

Proceed until N reaction rates have been input

* note: If all the rates are the same, only one value need be input as K(1) and the remaining values input as zero. The program has an internal test to see if K(2) is zero. If this is so, the program automatically sets all values of K equal to K(1). Only one card should be input when exercising this option and besides the value of K(1) the temperature correction factor should still be input.

** note: rates at 20° C

*** see page U-13

[RATE CARD #2] (Optional-for D.O. deficit only)

Columns	Variable	Description	Units	Format
(1-5)	FAC2	Temperature correction factor for second reaction rate (deoxygenation rate)		F5
(6-10)	FL	Ratio of ultimate to 5-day BOD		F5
(11-15)	KD(1)*	Deoxygenation rate for section 1**	1/day	F5
(16-20)	KD(2)	Deoxygenation rate for section 2	1/day	F5
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
(76-80)	KD(14)	Deoxygenation rate for section 14 (proceed until N rates have been input)	1/day	F5

[PHOTOSYNTHESIS RATE] (Optional for D.O. deficit only)***

(1-5)	PMR(1)	Net photosynthesis rate for section 1	mg/l/day	F5
(6-10)	PMR(2)	Net photosynthesis rate for section 2	mg/l/day	F5
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
(76-80)	PMR(16)	Net photosynthesis rate for section 16 (proceed until N rates have been input)	mg/l/day	F5

[BENTHAL DEOXYGENATION RATE] (Optional for D.O. deficit only)***

(1-5)	FAC3	Temperature correction factor for benthic demand		
(6-10)	BD(1)	Benthic demand for section 1**	gm/M ² /day	F5
(11-15)	BD(2)	Benthic demand for section 2	gm/M ² /day	F5
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
(76-80)	BD(15)	Benthic demand for section 15 (proceed until N rates have been input)	gm/M ² /day	F5

* As described on the previous page, if all rates are equal only KD(1) need be input and all other KD's can be left blank.

** rates at T=20° C

*** note: In an additive coupled run which calculates the deficit due to CBOD, the deficit due to NBOD and then adds them it is unnecessary to input the reaeration rates, the photosynthesis rate and the benthic demand with the NBOD part of the run. All such cards should be omitted rather than inputting them a second time. This is illustrated in the example problem which follows.

[LOAD CARDS]

Columns	Variable	Description	Units	Format
(1-10)	LOAD	LOAD to a section		F10
(11-13)	ISEC	Section to which LOAD is applied	#/day	I3

(note - Individual LOAD CARDS are needed for each LOAD input.
The last LOAD should be followed by a blank card which
indicates that the previous card was the last LOAD to be
input. If there are no loads merely input a blank card).

EXAMPLE PROBLEM

The following example problem is primarily intended to illustrate the input and output of HAR93. It should be noted that several simplifications have been made which would never be used in an actual modeling study and as such this example should not be used as a strict guide to applications of the program.

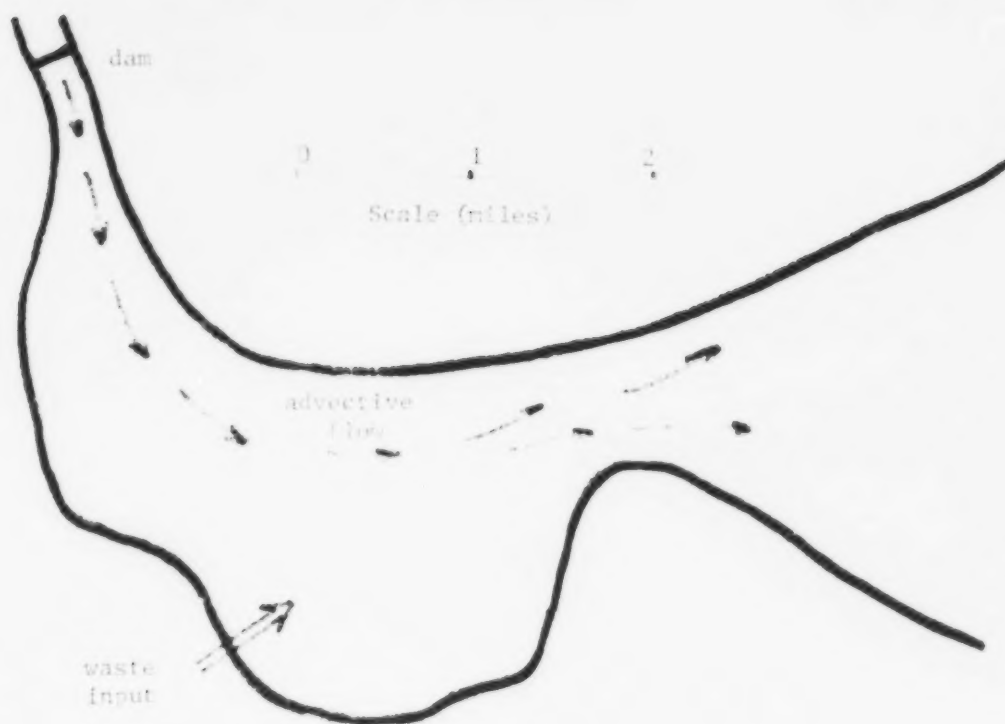


figure U-3: Overview of a fictitious tidal bay

The tidal bay depicted in figure U-3 has a dam situated at its head end and opens onto a large estuary at its mouth. As shown in figure U-4, the bay can be generally divided into a deep section on the north and shallow flats on the south. An investigation of the bays hydrodynamics has indicated that the fresh water flow entering the system over the dam makes its way to the sea along the northern coast and that relatively small amounts of water are transferred between the flats and the deeper section.



Figure U-4. Depth readings (feet) for the tidal bay

At present, a large municipality discharges raw sewage directly to the southwest corner of the bay resulting in critical depression of dissolved oxygen levels as shown in figure U-5. One question which might be addressed using HARO3 would be whether discharging the waste into the deeper area to the north would significantly improve the water quality?

Utilizing the available data, the segmentation scheme shown in figure U-6 was developed. Data for the segments is given in tables U-1 and U-2.

The results of the analysis is shown in figure U-7. As can be seen, discharge into the northern part of the bay significantly improves water quality by taking advantage of the additional dilution, transport and mixing which exist there.

A printout of the input cards is given in figure U-8 for the run in which the lead is discharged in the northern part of the bay. The corresponding output is also attached.



Figure D-5: "Glycolysis" as a correct for total (see D)

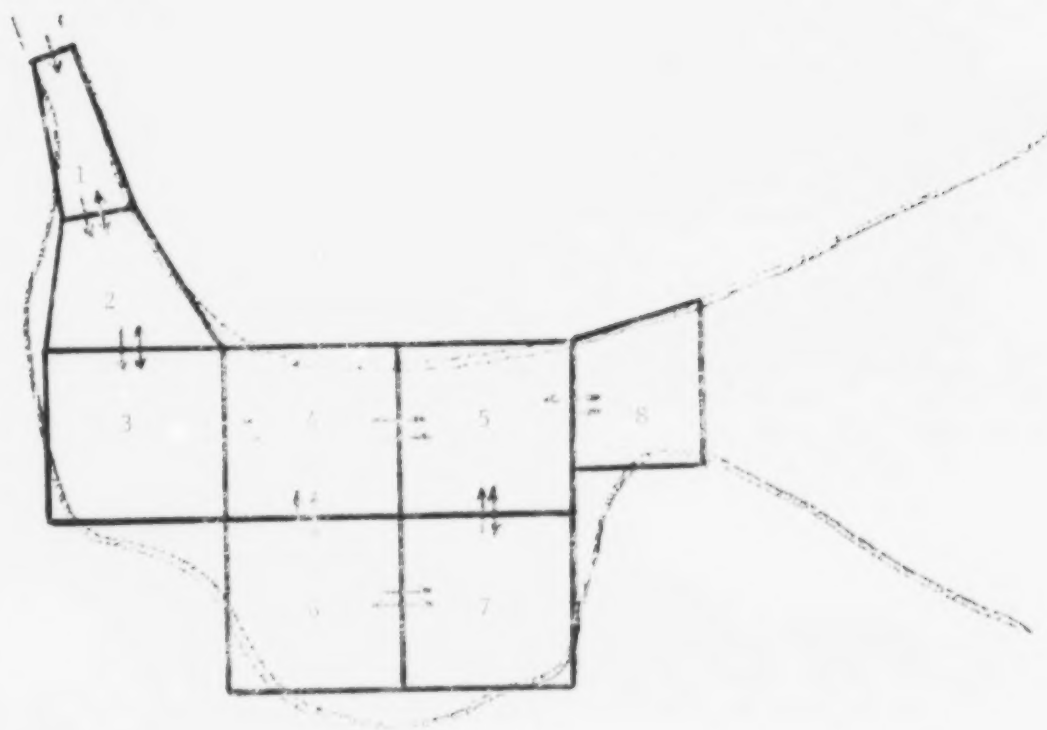


Figure E-6: Quantitative scheme for the bay
D-17

Interfaces

	1-1	1-2	2-3	3-4	4-5	4-6	6-7	5-7	5-8	8-8
Area (ft ²)		39600.	95040.	100320.	105600.	36960.	21200.	31680.	99000.	1584.
Dispersion (mile ² /day)		0.5	.5	1.0	1.0	0.5	0.5	0.5	1.5	1.5
Flow (cfs)	150.	150.	150.	150.	243.				243.	243.
Boundary condition (mg/l)										
Chlorides										
CBOD	2.									1000
SBOD	2.									.5
DO deficit	1.									.5

Table U-1: Interface data for run with load to section 4

Sections

	1	2	3	4	5	6	7	8
Temperature (°C)	21.0	22.0	22.0	22.0	22.0	4.0	24.0	22.0
Depth (feet)	12.0	13.0	15.0	20.0	22.0	4.0	5.0	30.0
Volume (10 ⁶ feet ³)	83.64	271.8	418.18	557.57	613.32	111.51	139.30	836.35
CBOD removal rate (l/day)	.3	.3	.3	.3	.3	.3	.3	.3
SBOD removal rate (l/day)	.3	.3	.3	.3	.3	.2	.3	.3
regeneration rate (l/day)	.24	.23	.22	.17	.15	.16	.18	.12
CBOD deoxygenation rate (l/day)	.1	.1	.1	.1	.1	.1	.1	.1
SBOD deoxygenation rate (l/day)	.1	.1	.1	.1	.1	.1	.1	.1
CBOD load (#/day)								
SBOD load (#/day)				100000.				
Benthic load (gm/m ² /day)				1000		.05		
Algal load (mg/l/day)								.25
Waste load flow (cfs)								

Table U-2: Section data with load to section 4

93.

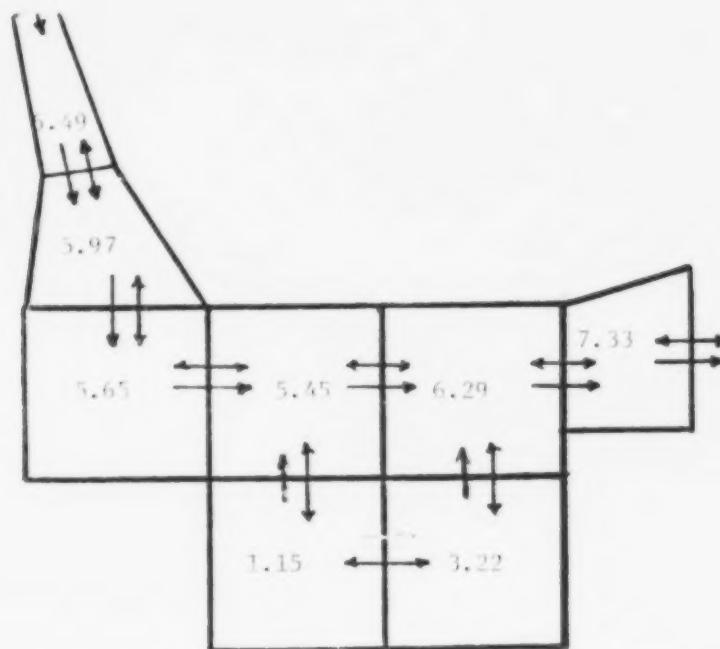


Figure U-7a: Results of model run with load to segment 6.

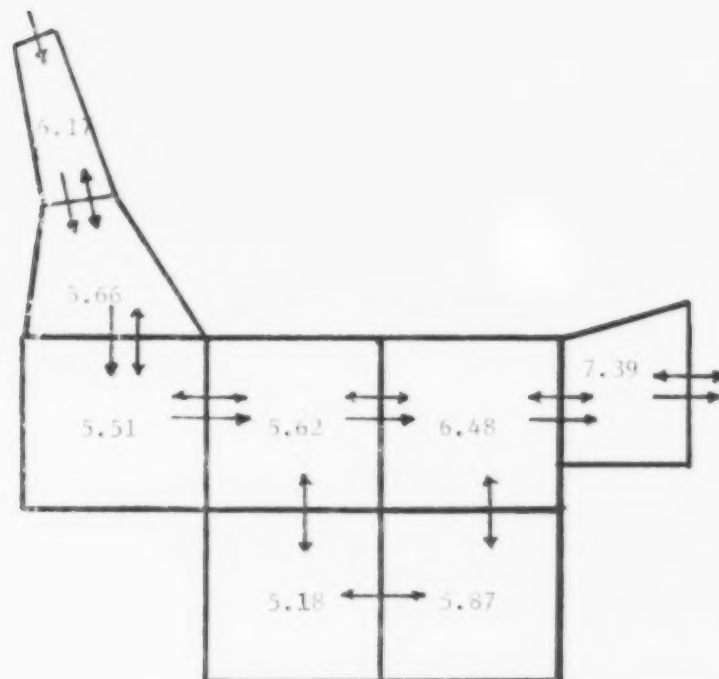


Figure U-7b: Results of model run with load to segment 4.

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

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1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

1.00000

Figure U-8: Input deck for exar run with load section 4

21.2	5	7
97.	1.5	263.
105.501.0	263.	536.96 .5
100.321.0	150.	4
95.04 .5	150.	3

EXAMPLE RUN (LOAD TO SECTION 4)

150. 139.6 0.5 150. 2 8 5 1000. 1. 1. 5200.

EXAMPLE RUN (LOAD TO SECTION 4)

••SYSTEM PARAMETERS••

NUMBER OF SECTIONS = 8 IPRINT = 0
ICON = 6 IPIGH = 0

••SCALE FACTORS••

SCALE(1) = 1000.000 SCALE(2) = 1.000 SCALE(3) = 1.000 SCALE(4) = 5280.000

INTERFACE ROW-SEG	AREA (FT ²)	E (MI ^{1/2} /D) (CFS)	Q (CFS)	INTERFACE ROW-SEG	AREA (FT ²)	E (MI ^{1/2} /D) (CFS)	Q (CFS)	INTERFACE ROW-SEG	AREA (FT ²)	E (MI ^{1/2} /D) (CFS)	Q (CFS)
(1-1)	0.	0.0	-150.0	(1-2)	39600.	0.500	150.0	(1-3)	0.	0.0	0.0
(1-0)	0.	0.0	0.0	(1-0)	0.	0.0	0.0	(1-0)	0.	0.0	0.0
(2-3)	95040.	0.500	150.0	(2-1)	39600.	0.500	-150.0	(2-0)	0.	0.0	0.0
(2-0)	0.	0.0	0.0	(2-0)	0.	0.0	0.0	(2-0)	0.	0.0	0.0
(3-4)	100320.	1.000	150.0	(3-2)	95040.	0.500	-150.0	(3-0)	0.	0.0	0.0
(3-0)	0.	0.0	0.0	(3-0)	0.	0.0	0.0	(3-0)	0.	0.0	0.0
(4-5)	105600.	1.000	243.0	(4-6)	36760.	0.500	0.0	(4-3)	100320.	1.500	-150.0
(4-0)	0.	0.0	0.0	(4-0)	0.	0.0	0.0	(4-0)	0.	0.0	0.0
(5-8)	99000.	1.500	243.0	(5-7)	31600.	0.500	0.0	(5-4)	105600.	1.500	-243.0
(5-0)	0.	0.0	0.0	(5-0)	0.	0.0	0.0	(5-0)	0.	0.0	0.0
(6-7)	21200.	0.500	0.0	(6-4)	36760.	0.500	0.0	(6-0)	0.	0.0	0.0
(6-0)	0.	0.0	0.0	(6-0)	0.	0.0	0.0	(6-0)	0.	0.0	0.0
(7-5)	31680.	0.500	0.0	(7-6)	21200.	0.500	0.0	(7-0)	0.	0.0	0.0
(7-0)	0.	0.0	0.0	(7-0)	0.	0.0	0.0	(7-0)	0.	0.0	0.0
(8-8)	158400.	1.500	243.0	(8-5)	99000.	1.500	-243.0	(8-0)	0.	0.0	0.0
(8-0)	0.	0.0	0.0	(8-0)	0.	0.0	0.0	(8-0)	0.	0.0	0.0

INTERFACE		LENGTH	INTERFACE		LENGTH	INTERFACE		LENGTH	INTERFACE		LENGTH
1-1	5280.		1-2	5280.		1-0	0.		1-0	0.	
2-1	5280.		2-3	5280.		2-0	0.		2-0	0.	
3-1	5280.		3-4	5280.		3-0	0.		3-0	0.	
4-3	5280.		4-5	5280.		4-6	5280.		4-0	0.	
5-4	5280.		5-8	5280.		5-7	5280.		5-0	0.	
6-4	5280.		6-7	5280.		6-0	0.		6-0	0.	
7-5	5280.		7-6	5280.		7-0	0.		7-0	0.	
8-5	5280.		8-8	5280.		8-0	0.		8-0	0.	

SECTION 6 HAS AN EXCESS FLOW OF 92.99798 CFS

VALUES OF ALPHA AND EPRIM

INTRFC	EPRIM ALPHA (MCD)	INTRFC	EPRIM ALPHA (MCD)	INTRFC	EPRIM ALPHA (MCD)	INTRFC	EPRIM ALPHA (MCD)	INTRFC	EPRIM ALPHA (MCD)	INTRFC	EPRIM ALPHA (MCD)
1-1	0.1000	1-2	782.0500	1-0	0.00	1-0	0.00	1-0	0.00	1-0	0.00
2-3	1877.0500	2-1	782.0500	2-0	0.00	2-0	0.00	2-0	0.00	2-0	0.00
3-4	3963.0500	3-2	1877.0500	3-0	0.00	3-0	0.00	3-0	0.00	3-0	0.00
4-5	4171.0500	4-6	730.0500	4-3	3963.0500	4-0	0.00	4-0	0.00	4-0	0.00
5-8	5856.0500	5-7	626.0500	5-4	4171.0500	5-0	0.00	5-0	0.00	5-0	0.00
6-9	419.0500	6-4	730.0500	6-0	0.00	6-0	0.00	6-0	0.00	6-0	0.00
7-5	626.0500	7-6	619.0500	7-0	0.00	7-0	0.00	7-0	0.00	7-0	0.00
8-6	9385.0500	8-5	5856.0500	8-0	0.00	8-0	0.00	8-0	0.00	8-0	0.00

	SECTION TEMPERATURE (C)	VOLUME (10*6GAL)	DEPTH (FT)
1	21.00	625.63	12.00
2	22.00	2031.06	13.00
3	22.00	3127.99	15.00
4	22.00	4170.62	20.00
5	22.00	4587.63	22.00
6	24.00	834.09	4.00
7	24.00	1042.64	5.00
8	22.00	6255.89	30.00

SEGMENT CL BOUNDARY CONDITION(MG/L)
1 0.0
8 1000.00

SECTION CHLORIDE BOUNDARY LOAD (MG/CM/L)

1	0.0
2	0.0
3	0.0
4	0.0
5	0.0
6	0.0
7	0.0
8	930651.00

SECTION	CHLORIDES (MG/L)
1	755.843
2	956.837
3	901.211
4	923.532
5	957.424
6	932.199
7	947.311
8	983.405

SEGMENT BOD BOUNDARY CONDITION(G/L)
1 2.00
8 0.50

800 LOAD = 10000. POUNDS/DAY FOR SECTION *

THE TEMPERATURE CORRECTION FACTOR FOR THE BOD REMOVAL RATE = 1.047

SECTION	BOD REM RATE •TEMP CORR•	BOD WASTE LOAD (MGD•MG/L)	BOD MOUNDARY LOAD (MGD•MG/L)
1	0.156	0.0	191.490
2	0.184	0.0	0.0
3	0.184	0.0	0.0
4	0.184	1190.406	0.0
5	0.184	0.0	0.0
6	0.421	0.0	0.0
7	0.421	0.0	0.0
8	0.194	0.0	4651.784

SECTION	ROUTING/L1
1	0.059
2	1.035
3	1.538
4	2.257
5	1.112
6	1.335
7	0.846
8	0.638

SEGMENT DEF BOUNDARY CONDITION(G/L)
1 0
0.50
0.50

THE TEMPERATURE CORRECTION FACTOR FOR THE REGENERATION RATE = 1.024
 THE QCD CORRECTION FACTOR (FL) = 1.000
 THE TEMPERATURE CORRECTION FACTOR FOR THE INITIAL DEMAND = 1.080
 THE TEMP CORR FACTOR FOR RD = 1.047

SECTION	DIGR RATE °TEMP CORR	REGR RATE °TEMP CORR	BOUND COND LOAD (MGD/MG/L)	TOTAL LOAD (MG/L+MG/L)	PMR MG/L/D	RE °TEMP CORR
1	0.366	0.246	68.472	294.649	0.0	0.0
2	0.384	0.241	0.0	607.256	0.0	0.0
3	0.384	0.231	0.0	1845.240	0.0	0.0
4	0.384	0.178	0.0	9611.576	0.0	0.0
5	0.384	0.177	0.0	1967.216	0.0	0.0
6	0.421	0.176	0.0	516.488	0.0	0.098
7	0.421	0.178	0.0	110.375	0.250	0.0
8	0.364	0.126	4653.239	6184.867	0.0	0.0

SECTION	DEFICITING/LI
1	1.543
2	1.858
3	2.012
4	1.787
5	1.569
6	2.000
7	1.472
8	0.930

SECTION	CHLORIDES	TEMPERATURE	DEFICIT	SATURATION	DO
1	755.94	21.00	1.56	8.78	7.19
2	855.84	22.00	1.86	8.60	6.76
3	901.21	22.00	2.01	8.60	6.50
4	923.53	27.00	1.99	8.59	6.61
5	957.62	27.00	1.87	8.59	7.12
6	932.20	26.00	2.00	8.76	6.26
7	947.31	26.00	1.59	8.76	6.77
8	983.40	22.00	0.93	8.59	7.66

4 800 LOAD = 100000 POUNDS/DAY FOR SECTION 4

THE TEMPERATURE CORRECTION FACTOR FOR THE BOD REMOVAL RATE = 1.090

SECTION	BOD REM RATE °TEMP CORRE	BOD WASTE LOAD (MGD*°F/L)	BOD BOUNDARY LOAD (MGD*°F/L)
1	0.108	0.0	193.890
2	0.117	0.0	0.0
3	0.117	0.0	0.0
4	0.117	11990.406	0.0
5	0.117	0.0	0.0
6	0.136	0.0	0.0
7	0.136	0.0	0.0
8	0.117	0.0	0.0

SECTION	BOD (MG/L)
1	2.369
2	2.635
3	3.098
4	3.615
5	1.832
6	2.731
7	1.930
8	0.681

SEGMENT	DEF. BOUNDARY CONDITION(MG/L)
1	0.0
8	0.0

THE TEMPERATURE CORRECTION FACTOR FOR THE REGENERATION RATE = 1.024
 THE BOD CORRECTION FACTOR (fL) = 1.000
 THE TEMPERATURE CORRECTION FACTOR FOR THE BENTHAL DEMAND = 1.090
 THE TEMP CORR FACTOR FOR KD = 1.080

SECTION	DEUX RATE •TEMP CORR•	REAER RATE •TEMP CORR•	BOUND COND LOAD (MGD•M ³ /L)	TOTAL LOAD (MGD•M ³ /L)	PMK MG/L/D	ED •TEMP CORR•
1	0.108	0.246	0.0	160.041	0.0	0.0
2	0.117	0.241	0.0	624.963	0.0	0.0
3	0.117	0.231	0.0	1130.566	0.0	0.0
4	0.117	0.178	0.0	1758.574	0.0	0.0
5	0.117	0.157	0.0	910.310	0.0	0.0
6	0.136	0.176	0.0	309.320	0.0	0.0
7	0.136	0.198	0.0	273.810	0.0	0.0
8	0.117	0.125	0.0	597.244	0.0	0.0

SECTION	DEFICITING/LI
1	0.955
2	1.077
3	1.075
4	0.983
5	0.639
6	1.085
7	0.902
8	0.268

RESULTS FOR COMBINED ICARBOHYDROUS AND NITROGENOUS J RUN

SECTION	CHLORIDES (MG/L)	TEMPERATURE (C)	DEFICIT (MG/L)	SATURATION (MG/L)	DO (MG/L)
1	755.94	21.00	2.61	8.78	6.17
2	855.84	22.00	2.96	8.63	5.66
3	901.21	22.00	3.03	8.60	5.51
4	923.53	22.00	2.97	8.59	5.62
5	957.42	22.00	2.11	8.59	6.48
6	932.20	24.00	3.08	8.26	5.18
7	947.31	24.00	2.39	8.26	5.87
8	983.40	22.00	1.20	8.53	7.39

JOB CONTROL LANGUAGE

The following JCL statements apply to users of HAR03 at OSI computer facilities:

```
//INTHAR03 JOB (ACNT,INT,2,5),PROGNAME  
//JOB LIB DD UNIT=3330,VOL=SER=BCS025,DISP=SHR,DSN=CHAPRA.xxxxx  
//STEP1 EXEC PGM=MODEL,REGION=nnnK  
//GO.FT07F001 DD SYSOUT=B  
//GO.FT06F001 DD SYSOUT=A  
//GO.FT05F001 DD *
```

Place data cards here

/*

Note:

xxxxx - HA100 for 100 segment model
 HA200 for 200 segment model
 HA50 for 50 segment model

nnn - 76 K for 50 segment model
 148 K for 100 segment model
 410 K for 200 segment model

INT - OSI user initials
ACNT - OSI account

Restrictions

- 1) HAR03 is presently limited to a system of 200 segments
- 2) A section may have only one interface act as a boundary
- 3) Each section may have up to six interfaces

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The Computer Program

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NOMENCLATURE

SYMBOL		DEFINITION	UNITS *
Documentation	Computer Program		
A	AREA (J) or ARRAY (I,JJ), where JJ=1,4,7,10,13,16 J=1,6 I=1,N	Cross-sectional area	L^2
[A]	AC(I,J) I=1,N J=1,N	Single system matrix. A matrix which represents a single substance which decays with first order kinetics (see page T-9)	L^3/T
[A] ⁻¹	AC(I,J) I=1,N J=1,N	Single system response matrix. The inverse of [A], this matrix represents the response of the system to the input of a load of a single substance decaying with first order kinetics (see page T-10)	$[(M/L^3)/(M/T)]$
[AB] or AB	AB(I,J) I=1,N J=1,N	The system matrix. Since matrices [A] and [B] differ only in a reaction term in their diagonals, a matrix without such a term has been formulated and is called the system matrix (see page T-15)	L^3/T
AC	AC(I,J) I=1,N J=1,N	The specific constituent matrix. When the appropriate reaction term is added to the diagonal of the system matrix the matrix for a specific constituent is generated. In the theory they were called [A] or [B]. As well, the term AC is used in the computer program to represent the matrix after it has been inverted.	L^3/T $[(M/L^3)/(M/T)]$
[B]	AC(I,J) I=1,N J=1,6	A matrix which represents the second substance of coupled set of constituents which react with first order kinetics (see page T-11)	M/L^3
[B] ⁻¹	AC(I,J) I=1,N J=1,6	The inverse of [B], this matrix represents the response of the system to the input of a load of the second substance of a coupled set of constituents.	$[(M/L^3)/(M/T)]$
BD	BD(I) I=1,N	Benthal oxygen demand	$M/L^2/T$
BOD		Biochemical oxygen demand	M/L^3
c		concentration of a constituent	M/L^3

* units; T=time, L=length, M=mass

SYMBOL		DEFINITION	UNITS
Documentation	Computer Program		
[C]	-1	The total system response matrix relates input of the first substance in a coupled set of reactants to the response of the second constituent.	$[(M/L^3)/(M/T)]$
CBOD		Component of BOD due primarily to oxygen utilized by suprophytic organisms as they utilize the carbonaceous matter in a waste	M/L^3
D		Dissolved oxygen deficit = the saturation value minus the actual concentration of dissolved oxygen = $DO_s - DO$	M/L^3
D_0		The initial concentration of dissolved oxygen deficit at the point introduction of waste into a stream.	M/L^3
DO		Concentration of dissolved oxygen	M/L^3
DO_s	CS	Saturation concentration of dissolved oxygen	M/L^3
E	E(J) ARRAY(I, JJ + 1) where I=1, N J=1, 6 JJ=1, 4, 7, 10, 13, 16	Longitudinal dispersion coefficient	L^2/T
E'	EPRIM(C) J=1 6	Bulk dispersion coefficient =EA/l	L^3/T
H	H	depth	L
k or K		First order reaction coefficient, (also used to designate a section)	1/T
K_a	KA	Reaeration rate (first order)	1/T
K_d	KD	Deoxygenation rate (first order)	1/T
K_r	KA	BOD removal rate (first order)	1/T

SYMBOL		DEFINITION	UNITS
Documentation	Computer Program		
1		section length	L
L_o		Initial concentration of BOD at point of introduction of a waste into a stream.	M/L ³
NBOD		Nitrogenous component of BOD primarily caused by autotrophic bacteria utilizing nitrogen in waste.	M/L ³
PMR	PMP	Net algal oxygen rate = photosynthesis effect - respiration effect of algae on oxygen	M/L ³ /T
Q	Q(J) ARRAY(1,JJ+2) where J=1,6 I=1,N JJ=1,4,7,10, 13,16	net advective flow	L ³ /T
t		time	T
T	T(I)	temperature	° C
U		advective velocity	L/T

SYMBOL		DEFINITION	UNITS
Documentation	Computer Program		
vol	VOL	Volume	L
W	W	Waste load of a constituent	M/T
W_b		Deficit waste load	M/T
W_c		BOD waste load	M/T
x		Distance	L
Y	Y	Dissolved oxygen deficit waste load	M/L ³
α	ALPHA	weighting coefficient used in the approximation scheme of the model.	
β	1-ALPHA	weighting coefficient = 1- α	

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